Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 7, 2016

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Background

By letter dated June 12, 2015, the Lower Passaic River Study Area ("LPRSA") Cooperating Parties Group (CPG) invoked dispute resolution under Paragraph 64 of the Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study ("RI/FS Settlement Agreement") for the LPRSA. The dispute resolution concerns the June 1, 2015 letter issued by the U.S. Environmental Protection Agency (EPA), Region 2, concluding that the existing RI data from the top six inches (approximately 15 centimeters (cm)) of sediment, and model concentration simulations results for this depth interval, should be used to represent contaminant concentrations applicable to biological exposure depth in the bioaccumulation model being developed for the 17 Mile RI/FS to predict future contaminant concentrations in biota post-remediation.

EPA responded to the June 12, 2015 notice by letter dated June 25, 2015, asking the CPG for a Dispute Resolution Statement of objections and indicating that EPA would work with the CPG to attempt to resolve the dispute. EPA also indicated that on receipt of the detailed written statement, EPA could determine whether to extend the Negotiation Period called for in Paragraph 64 of the RI/FS Settlement Agreement.

The CPG responded on July 2, 2015, not with a detailed statement, but with a request for additional information reviewed by EPA in preparing its June 1, 2015 letter. On July 9, 2015, EPA provided additional information and again requested a detailed statement. EPA allowed the Negotiation Period to continue.

On August 18, 2015, the CPG contacted EPA to initiate a discussion regarding additional sampling, as suggested by EPA in its June 1, 2015 letter, and on August 26, 2015 the CPG presented its proposed additional sampling program to EPA via teleconference. The CPG plan included direct measurement of benthic organism biomass data and benthic organism tissue concentrations, but not sediment sampling. The CPG requested that Region 2 let it know quickly if EPA could support the program as described or if it had significant reservations. Responding to this request, EPA informed the CPG on September 1, 2015 that a more robust program (multi-seasonal survey) that included sediment sampling would need to be developed if EPA were to support it.

The CPG then asked EPA to review the draft Quality Assurance Project Plan (QAPP) worksheets it was developing for this work prior to deciding whether the scope of the program was sufficient, suggesting they would plan to sample in fall 2015 if it was. The CPG submitted those worksheets on September 17, 2015, and EPA reviewed the worksheets in sufficient detail to determine that the program was not sufficient. EPA discussed its feedback with the CPG on October 8, 2015, and the CPG asked that EPA provide its major concerns in writing. These were provided in EPA's letter dated October 23, 2015.

While EPA was preparing the October 23, 2015 letter, the CPG submitted a letter dated October 16, 2015, taking issue with EPA's oral feedback, questioning EPA's basis for allowing for any Partner Agency review of the CPG's proposed sampling program, and expressing doubt about EPA's sincerity. EPA responded to these concerns, as well, in its October 23, 2015 letter. Based on the CPG's expression of deep dissatisfaction with the informal negotiation process, EPA questioned whether the discussions were achieving the intended purpose of resolving the disagreement between EPA and the CPG, and indicated plans to present the dispute to the Regional decision-maker.

On November 13, 2015, the CPG submitted the detailed Dispute Resolution Statement that EPA had requested on June 25, 2015. Though the dispute had begun in June, the CPG argued that "the Region's arguments have continued through the nearly 2 years of this issue." Despite the substantial mischaracterizations of EPA's exchanges with the CPG, the CPG suggested "a series of meaningful and substantive face-to-face meetings with experts from Region 2, EPA Headquarters, and the CPG." The CPG's letter addressed not just the issue in dispute, but EPA's comments on the sufficiency of the CPG's proposed sampling program – which is not the subject of this dispute.

By letter dated November 19, 2015, EPA informed the CPG that it would review the Dispute Resolution Statement and evaluate if there were any basis for further discussions. On January 13, 2016, EPA, having reviewed the Dispute Resolution Statement, informed the CPG that it had concluded that the most productive path forward at this time is to end the Negotiation Period and submit this matter to Walter Mugdan, the Director of the Emergency and Remedial Response Division (ERRD), who will be the decision-maker.

By letter dated January 28, 2016, the CPG wrote to discuss the EPA Office of Research and Development guidance published in October 2015, which the CPG argued supports its conclusion that the BAZ is "generally less than 10 cm." Based on the guidance, the CPG proposed to utilize an "interim map of exposure depths following consultation and review with Region 2" to be validated and updated using data collected as part of a field sampling program under Region 2 oversight in spring 2016.

Though Region 2 is encouraged by the CPG's recent less contentious tone in its letter dated January 28, 2016, the discouraging results of Region 2's efforts to reach common ground with the CPG over the last eight months have led staff to conclude that it is appropriate for the decision-maker to review the positions and make a determination. Further discussions have a high potential to be unproductive.

Relevant documents are attached hereto as exhibits, as follows:

Exhibit A:	June 1, 2015 letter from EPA to CPG, explaining why CPG should use 15 cm depth horizon ("June 1, 2015 EPA letter").
Exhibit B:	June 12, 2015 letter from CPG to EPA, invoking dispute resolution.
Exhibit C:	June 25, 2015 letter from EPA to CPG, requesting detailed statement of dispute.
Exhibit D:	July 2, 2015 letter from CPG to EPA, requesting that EPA provide additional material reviewed by EPA in preparing the June 1, 2015 letter.
Exhibit E:	July 9, 2015 letter from EPA to CPG, providing additional information.
Exhibit F:	September 17, 2016 email from CPG to EPA transmitting QAPP work sheets.
Exhibit G:	October 16, 2015 letter from CPG to EPA.
Exhibit H:	October 23, letter from EPA to CPG.

Exhibit I:	November 13, 2015 letter from CPG to EPA, transmitting Statement of Position.
Exhibit J:	November 19, 2015 letter from EPA to CPG.
Exhibit K:	January 13, 2016 letter from EPA to CPG.
Exhibit L:	January 28, 2016 letter from CPG to EPA transmitting EPA technical document dated October 2015 and arguing that EPA should suspend the dispute resolution process for further discussions with CPG.

Issue in Dispute

Whether, as Regional staff has directed, the existing RI data from the top six inches (approximately 15 cm) of sediment, and model concentration simulations results for this depth interval, should be used to represent contaminant concentrations applicable to biological exposure depth in the bioaccumulation model being developed for the 17 Mile RI/FS to predict future contaminant concentrations in biota post-remediation.

In contrast, the CPG proposed to use 2 cm as the benthic exposure zone, and to do so by utilizing contaminant concentration simulation results averaged over the 2 cm depth in the bioaccumulation model.

The CPG Dispute Statement provides that there are two areas of disagreement between Region 2 and the CPG: 1) the depth at which the majority of benthic invertebrates feed and reside in the sediment bed of the LPRSA; and 2) the reliability and certainty of sediment chemistry concentration predictions for depth interval of less than 15 cm, or approximately 6 inches. In Region 2's view, the issue raised and disputed by CPG in their June 12, 2016 letter is the proposal to use 2 cm as the benthic community exposure depth. The reliability of the contaminant fate and transport model to calculate concentrations in the top 2 cm is relevant to the Region's conclusion. Region 2 has reiterated its explanation below, but does not agree that this dispute should be broadened to a dispute about modeling, which, under the RI/FS Settlement Agreement is explicitly disallowed.

Executive Summary – Region 2 Position

After careful consideration of all information presented by the CPG and developed by EPA regarding this dispute and discussions with Agency and consultant experts, Region 2 has concluded that the 15 cm depth horizon is most appropriate to represent contaminant concentrations in the benthic community exposure zone for use in the 17 Mile RI/FS bioaccumulation model.

As described in more detail below, the Region disagrees with the CPG's interpretation of results from the June 2005 sediment profile Imaging (SPI) as the central basis for proposing a 2 cm benthic exposure zone. The SPI data were collected at a single point in time and not for the purpose of determining the depth of exposure. Due to sediment deposition and erosion, sediment mixing by benthic macroinvertebrates and fish, and documented sediment contamination, a 15 cm benthic exposure zone is appropriate to fully characterize and model future exposures. While still relatively thin, a 15 cm benthic exposure zone accounts for variability due to erosion, deposition, and other factors, in contrast to 2 cm, which is a resolution that cannot be tested in the model with the current dataset.

Furthermore, surface sediment sampling of the LPRSA has been performed over a number of years and phases, with the data use objective that a composited sample from the top 15 cm is representative of surface sediment concentrations across the entire sample depth, and accordingly over 500 samples have been collected. This robust empirical dataset is critical to calibrating the contaminant fate and transport model, and should also be used for predicting future sediment concentrations for use in the bioaccumulation model. Conversely, the 8 samples with data from the top 2 cm show variable vertical gradients over the top 15 cm, with increasing concentrations with depth in some, decreasing concentrations in others, and oscillating concentrations in the remainder. Reliance on such a limited and variable dataset to model future sediment concentrations in the top 2 cm would introduce unacceptable uncertainty going forward.

Biological Exposure Depth Discussion

In disputing EPA's instructions, the CPG relies heavily on the sediment profile imaging (SPI) data collected in June 2005. The survey was conducted 10 years ago by Germano & Associates, Inc. on behalf of the USACE and NJDOT to support their restoration planning, not by EPA as part of the LPRSA RI/FS, and the purpose of the survey was not to determine the depth of exposure for the LPRSA. SPI is a reconnaissance tool that can map gradients in sediment type, biological communities, and disturbances from physical forces or organic enrichment. During the June 2005 SPI survey, a sediment profile camera that works like an inverted periscope was utilized over a five-day period to take images of surface sediment across transects along the lower Passaic River. There are limitations with the SPI survey with respect to assumptions about the presence or absence of biological communities (i.e., benthic invertebrates). These include the random placement of transects (i.e., not selected based on habitat quality), spatial distribution of the benthic invertebrates, limitations of the SPI methodology when used as a single measurement point in time, temporal variation in mobility of invertebrates (e.g., tidal stage, time of day, season) and movement of surface sediments (e.g., tidal fluctuation, erosion, deposition), or avoidance of chemical contamination by benthic invertebrates.

The CPG argues that the SPI data showed that the redox potential discontinuity (RPD), which represents the vertical boundary between the upper oxic and lower anoxic sediments, was relatively shallow in the LPRSA, averaging 1.6 cm in the upper estuary (River Mile [RM] 0 to 4), 1.7 cm in the transition zone (RM 4 to 13), and 2.1 in the tidal freshwater zone (RM 13 to 17.4). The CPG states that this dataset provides ample evidence that the top 2 cm of sediment is the zone where the majority of invertebrates reside and the zone that serves as a food source for invertivorous fish. The CPG terms this zone as the benthic exposure zone (BEZ). They distinguish the BEZ from the biologically active zone (BAZ), which they describe as the maximum depth to which biological activity occurs. In the CPG's view, the 2 cm BEZ should be viewed as a subset of the BAZ. The CPG concludes that most of the benthic invertebrates are concentrated above the RPD, whereas they agreed that "in very limited instances" biological activity is found below the 2 cm BEZ. According to the CPG, the recently-released EPA (2015) peer-reviewed technical document is consistent with their interpretation of the SPI data, that biological activity rarely appeared to extend beyond the upper several cm of sediment, which the US EPA document would round up to 5 cm.

EPA does not agree that the depth of the RPD correlates with the BEZ. The CPG states that since the averages of RPDs from the SPI data are approximately 2 cm across the three different zones (i.e., upper estuary, transition zone, and tidal freshwater zone) of the LPRSA, sampling below 2 cm is not necessary. However, Sturdivant et al. (2012) reported that infaunal burrow depths in the tidal (mesohaline) portion of the Rappahannock River (VA), on average, extended approximately 2 cm below the RPD, and that the depth of the RPD was highly dependent upon bottom-water dissolved oxygen (DO) concentrations. Surface water DO is expected to vary substantially diurnally and seasonally, suggesting that the RPD is temporally highly variable. Charonneau and Hare (1998) also found that burrowing depths varied seasonally in a freshwater lake in Quebec, and that, on average, chironomids burrowed to approximately 7.5 cm (Figure 1). Moreover, contrary to the CPG's suggestion, the EPA (2015) technical document indicates that macroinvertebrates can span both oxic and anoxic layers of sediment. Therefore, the use of the RPD as a boundary for exposure is technically too restrictive and likely not valid. The 2015 EPA technical document further clarifies that organisms that feed in anoxic layers upwardly transport subsurface material (including pollutants), further supporting the need to include sediment concentrations from deeper depths.

Further, even if the hypothesis that the majority of benthic macroinvertebrates currently reside in the upper 2 cm of the sediment profile were valid, this may be due to contaminant avoidance rather than the inability to burrow deeper or preference for upper sediments. The 2005 SPI data showed that there were much deeper feeding voids throughout the LPRSA (in 13% of images, 14% of stations) with a mean (±S.D.) of 6.6 ± 3.7 cm, indicating the potential for deeper penetration by benthic organisms. Feeding void depths ranged down to 13.4 cm. The absence of benthic invertebrates in these voids may be due to low population density, the snapshot methodology of the SPI method, mobility of the organism, timing of the test, the historic record of the SPI method, or avoidance of chemical contamination, as discussed above. In Table 5.2 of the CPG's draft Baseline Ecological Risk Assessment (BERA) dated June 13, 2014 on pages 216-219, several chemicals of potential ecological concern (COPECs) are identified in the 0-15 cm sediment samples. De Lange et al. (2006) showed that two freshwater invertebrates (*Gammarus pulex* and *Asellus aquaticus*) actively avoided polycyclic aromatic hydrocarbon (PAH) contaminated sediments in laboratory exposures. West and Ankley (1998) similarly found that the freshwater oligochaete (*Lumbriculus variegatus*) preferred reference sediments over sediments contaminated with PAHs, dichlorodiphenyltrichloroethane (DDT), or copper, all of which were identified as COPECs in the draft Screening Level Ecological Risk Assessment (SLERA), submitted as an appendix to the CPG's draft BERA dated June 13, 2014. Interestingly, contaminant concentrations in the assays conducted by De Lange et al. (2006) and West and Ankley (1998) were at levels previously shown to have little effect on survival and growth, suggesting that avoidance occurs before lethal or sublethal effects are observed. So, while these contaminants might not exceed toxicity reference values (TRVs), they may occur in concentrations high enough to elicit avoidance by benthic macroinvertebrates.

SPI data, along with the benthic macroinvertebrate and fish population data, suggest that biological and physical processes interact with more than the top 2 cm due to the dynamic benthic environment. Confining exposure to 2 cm based on a limited and focused study conducted 10 years ago (Germano & Associates 2005) ignores the complex and regularly changing sediment surface, as explained within that same study.

For example, one of the metrics obtained by Germano & Associates is the surface boundary roughness, which measures the distance of the sediment-water boundary across the prism used to capture the image. This boundary roughness is a representation of small-scale surface topography. This metric is addressed in detail in the SPI report, but is not addressed by the CPG. Values ranged from 0.4 to 12.8 cm at the brackish water stations and from 0.3 to 6.3 cm in the tidal freshwater stations. Additionally, the infaunal succession stage data suggest that the LPRSA benthic habitat is subject to regular periods of deposition and erosion – supporting the assumption of a dynamic surface sediment environment. This suggests that the sediment profile is in a regular state of flux. With such changes to the sediment topography, the actual depth of biological activity and contaminant exposure will continue to change (e.g., the 2-cm depth one day may be the 10-cm depth following sedimentation and vice-versa). It is reasonable to conclude that this demonstrates that the sediment profile is regularly mixing and changing. Using measured concentrations from the top 2 cm, which currently is only available for eight samples, would bias the future model predictions due to sediment profiles greater than 2 cm being reworked as surface sediments.

Fish that feed on benthic invertebrates also impact the top several centimeters of the sediment profile. Ritvo et al. (2004) reported that common carp (*Cyprinus carpio*) mixed the upper 3 to 5 cm of sediment, though Huser et al. (2016) pointed out that the sediment bulk density in that study was higher than other sediments. Huser et al. (2016), conversely, reported sediment mixing depths by *C. carpio* averaging 13.0 ± 3.7 cm in shallow lake sediments. While this study was not conducted within the LPRSA, it does highlight the fact that the carp have the potential to disrupt the sediment profile deeper than the BEZ proposed by the CPG. Ignoring contaminants below 2 cm will therefore underestimate exposures for some receptors, including abundant taxa such as carp. Other taxa of the LPRSA such as American eel, blue crab, and mummichog can also disturb surface sediments when foraging or wintering. For example, the American eel (*Anguilla rostrata*) burrows into the sediment surface head-first, and then uses body undulations to become fully buried. In some cases, the mouth can be up to 3.5 cm below the surface sediment, and their body is 7.39 cm below the sediment surface on average (Tomie et al. 2013). Mummichogs (*Fundulus heteroclitus*), in winter months, have been found to be completely burrowed in sediment cores (core depth of 15 cm) collected from pools adjacent to salt marshes (Rapaosa 2003). The interaction between blue crabs (*Callinectes sapidus*) and bivalve prey is also well documented. Blundon and Kennedy (1982) showed that clams had to burrow deeper than 10 cm to reduce predation by crabs, whereas Seitz et al. (2003) documented that blue crabs can feed on clams down to 5 to 6 cm under normal oxygen conditions, and as deep as 3.5 to 4 cm under hypoxic conditions. Additionally, sediment-associated organisms such as common carp, American eel, blue crab, and mummichog can affect the RPD due to disturbance of surface sediment below 2 cm, resulting in increased oxygen penetration within the sediment.

The recently released EPA (2015) peer-reviewed technical document for identifying appropriate sampling depths for risk assessment suggests that biological zones extend down to 5 cm at a minimum (oligohaline and polyhaline mud), and down to 15 cm in polyhaline sand and oligohaline mixed substrates (see enclosed Table 1 from US EPA 2015). These depths are based on benthic invertebrate abundance (80^{th} percentiles); however, sampling depths are deeper in most aquatic habitats when based on biomass (Figures 2 and 3 of this document). Salinity conditions of the LPRSA ranges from oligohaline to mesohaline, with substrates consisting of mud near the mouth of the river and more mixed substrates in the tidal freshwater segment (Germano & Associates 2005). These of course are subject to substrate variations, as well as differences in biological communities.

Currently, the dominance of specific species and feeding guilds in the LPRSA are based on biomass. However, biomass values used by the CPG to estimate dominance were obtained from data collected in the Chesapeake Bay [CB], wetlands along the Platte River in Nebraska, salt pans in the Margherita di Savoia, an estuary in Florida, an Arctic coastal tundra, and other places (page 10 of attachment 2 to Exhibit I). These biomass values were then applied to count data collected in the LPRSA, introducing bias and/or uncertainty into the estimation of biomass and dominance. For example, the bivalves *Macoma balthica* and *Corbicula* sp. were identified as the primary surface-feeding species. Based on 2009 benthic data from the CB (CBBMP 2016), *M. balthica* biomass averaged 0.15 grams (g) with a coefficient of variation (CV) of 276%, whereas *Corbicula* sp. averaged 0.67 g with a CV of 87%. With such high variation in invertebrate biomass from the CB, it can be assumed that similarly high variability is present in the benthic community in the Passaic River. Similarly, *Limnodrilus hoffmeisteri* was identified as the most abundant benthic invertebrate in the draft BERA dated June 13, 2014. Based on the 2009 CB dataset, only one individual of this species was collected with a biomass of 0.00035 g. No *L. hoffmeisteri* were collected in 2008 in the CB, and only one was collected in 2010 with a biomass of 0.00005 g. The inter-annual variation in abundance and the intra-annual variation in biomass suggest that site-specific data should be used where available, and that temporal variation warrants consideration.

Seasonal fluctuations in the RPD, as well as associated benthic macroinvertebrate abundance and diversity data, indicate that basing biological activity and contaminant exposure on SPI data from a single time-point is not defensible. Additionally, there is evidence that biological activity exists below 2 cm, and that contaminant concentrations are detectable down to 15 cm. As discussed above, the recently-released EPA (2015) technical document suggests that sampling in estuarine and tidal freshwater systems should extend to 10 to 15 cm – or possibly deeper depending on biomass of the community. The absence or reduced numbers of invertebrates below 2 cm might be attributable to contaminant avoidance, based on ample evidence of invertebrates actively avoiding sub-lethal concentrations in sediments across multiple habitat types.

LPRSA invertebrate biomass is currently unknown because biomass data were estimated using values obtained from multiple locations outside of the LPRSA. Therefore, the notion that site-specific data support CPG conclusions is misleading. Regardless of the actual invertebrate biomass in the LPRSA, this system experiences notable deposition and erosion events, thereby modifying the substrate and sediment column. In addition to the sediment mixing associated with deposition and erosion, carp and other species that feed on benthic macroinvertebrates actively forage within the upper several centimeters of sediment. In light of the multiple lines of evidence, the CPG's modeling of future scenarios of contaminant transport and release must consider modeling input data based on sediments deeper than 2 cm. EPA has concluded that the 15 cm depth horizon is most appropriate to represent contaminant concentrations in the benthic community exposure zone used in the 17-Mile RI/FS bioaccumulation model.

<u>Reliability and Certainty of Sediment Chemistry Concentration Predictions for Depth Interval of Less Than 15 cm by Sediment Transport and Contaminant Fate and Transport Model</u>

As stated in the June 1, 2015 letter, EPA concludes that average model results from the 15 cm horizon reasonably represent contaminant concentrations in the benthic community exposure zone. The model results do not reliably represent the top 2 cm. EPA's determinations with respect to the CPG's modeling work are not subject to dispute resolution, but provide context for the decision-maker.

Between 2005 and 2013, samples were collected from the top 6 inches of sediment at approximately 500 locations in the LPRSA (from Newark Bay to Dundee Dam) to support the 17-mile RI/FS. Sediment collected from eight of these locations was analyzed in 2 cm increments. Referring to these data, EPA explained that the concentration of 2,3,7,8-TCDD averaged over 15 cm compared to the concentration at the top 2 cm is highly variable. While this is not a statistically valid dataset from which to draw conclusions about contaminant concentrations within the 2 cm horizon across the river, the results do suggest that there are insufficient data from the top 2 cm to evaluate model performance.

Despite the fact that the limited dataset shows high variability, based on the modeling files provided to EPA in December 2014, the CPGs modeled predictions over 2 cm are consistently lower than those predicted over 15 cm on a reach averaged basis and over the vast majority of individual grid cells in the LPRSA. Over the duration of the 1995-2013 calibration period, the CPG's model predictions of 2,3,7,8-TCDD in the top 2 cm average less than half of the concentration in the top 15 cm. Given the variability in ratio of the 2 cm to 15 cm concentrations from the limited finely segmented dataset, EPA does not have confidence in these modeling results.

EPA has previously explained that the water column contaminant data do not provide a constraint on the 2 cm bed concentrations, because the water column concentrations are controlled by contaminant concentrations in the fluff layer and the CPG's model includes a parameter to control the transfer of contaminants between the upper layer of the bed and the fluff layer. The combination of the transfer parameter and contaminant concentrations in the upper layer of the bed (below the fluff layer) controls contaminant flux to the water column. This provides a non-unique link between the water column and the bed below the fluff layer. For example, alternative mixing and transfer parameters could reproduce the water column and 15 cm sediment data equally well with very different results for the top 2 cm of the bed. With different 2 cm bed concentrations the bioaccumulation model would be affected by these alternate choices.

The existing bathymetry change dataset cannot resolve changes as finely as 2 cm, due to factors including instrument accuracy and changes in surface sediment density (i.e., reflectiveness). The sediment transport model has been calibrated using the bathymetry change dataset, the accuracy of which is a direct function of the uncertainties of the individual bathymetry datasets, which means that the model cannot reliably predict bed elevation changes at scales as small as 2 cm. This means that there is no way to determine if the solids calculated to be present in the top 2 cm are, in fact, present in a particular grid cell or present but buried by subsequent deposition. Since the contaminant fate and transport model's predictions of contaminant concentrations are driven by bed characteristics passed to it by the sediment transport model, this inability to reliably predict bed elevation changes at 2 cm scales would further add to the uncertainty in the predicted contaminant concentrations in the 2 cm layer. The contaminant fate and transport model cannot be expected to produce reliable estimates of contaminants present in the top 2 cm if the sediment transport model cannot produce reliable estimates of the solids transport at this high level of vertical resolution.

Table 1 – Biologically Relevant Sediment Depths – Biotic Zones – for Decisions Related to Ecological Assessment or Remediation (Table 5 USEPA, 2015)

Habitat Type	Biotic Zone (cm)	Biotic zone (cm) (Considering Biomass)
Estuarine Intertidal		
Estuarine Intertidal Sand	15	
Estuarine Intertidal (Other Substrates)	*	
Estuarine Intertidal Poikilohaline	10	
Tidal Freshwater		
Tidal Freshwater Mixed Substrate	10	15
Estuarine Subtidal		
Oligohaline Sand	5	10
Mesohaline Sand	10	20
Polyhaline Sand	15	
Oligohaline Mud	5	5
Mesohaline Mud	10	25
Polyhaline Mud	5	*
Oligohaline Mixed Substrate	15	15
Mesohaline Mixed Substrate	10	30
Polyhaline Mixed Substrate	10	15
Lentic		
Lake Profundal Mud[a]	15	20
Lotic		
Stream Coarse Grained/Sand	35	
Stream Coarse Grained/Sand with Fines[b]	25	
River Coarse Grained/Sand with Fines[b]	15	
Marine Coastal		
Sand	5	20
Mud	15	15
Mixed Substrate	10	15
Marine Offshore		
Sand	10	20
Mud	15	20
Mixed Substrate	*	*

[*]Biotic zone not estimated because based on only one data set.
[a]Biotic zones for this category are based on oligochaetes.
[b]Fines denote grain sizes <2 mm in substantial quantity (approximately 20% or more by weight).

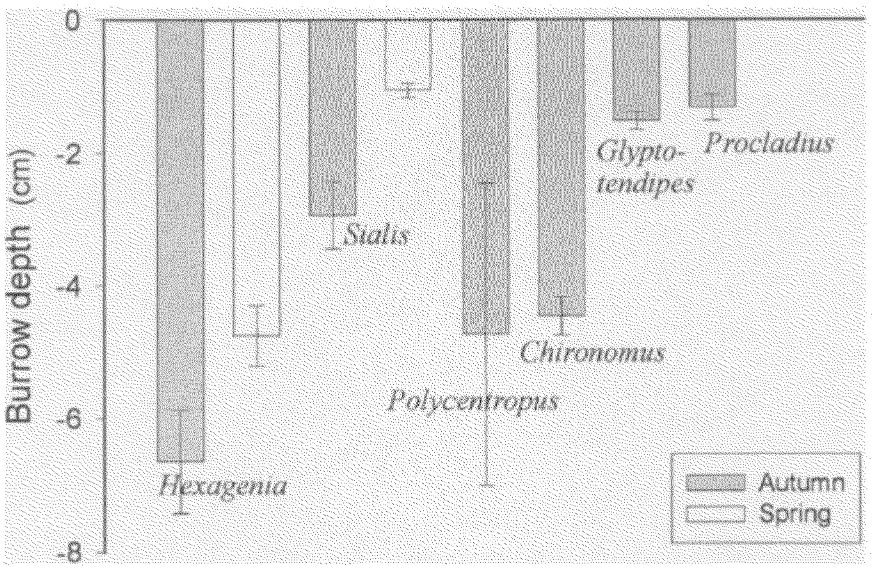

FIG. 2. Mean (±1 SE) depths to which the study taxa burrowed based on the maximum value for each individual recorded during a 3-d observation period. Both autumn and spring values are shown for *Hexagenia limbata* and *Sialis velata*, whereas autumn values only are shown for the other taxa.

Figure 1. Seasonal variations in burrowing depths of multiple freshwater invertebrates. (from Charonneau and Hare (1998)).

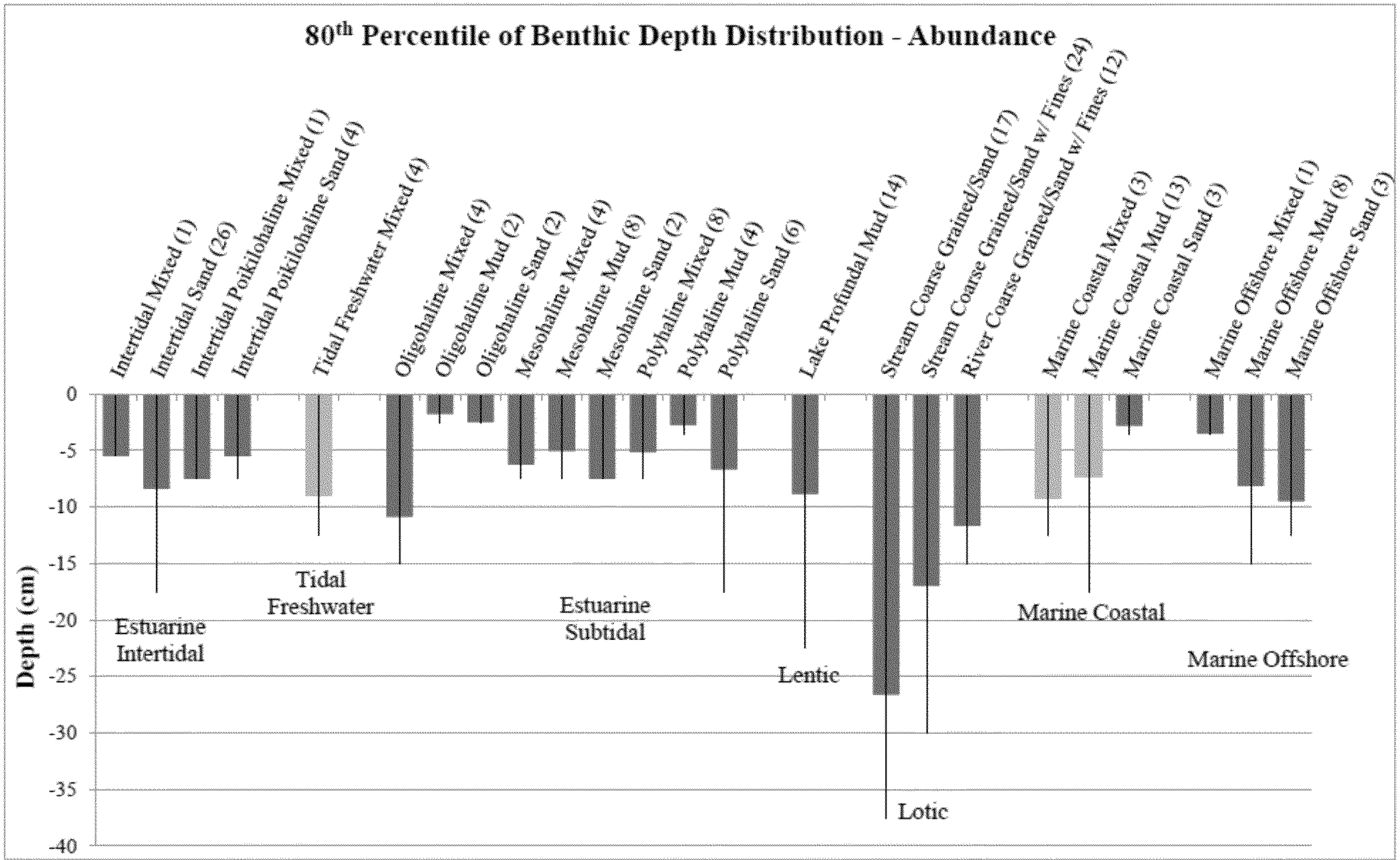

Figure 3. Mean 80th Percentile of Benthic Abundance Depth Distribution (+ Maximum 80th Percentile) in Various Habitats. Number of data sets in parentheses (the number of cores comprising data sets from each habitat type is noted in Table 4). Also see Table 4 for data locations.

Figure 2. Distribution by depth of benthic macroinvertebrates based on abundance (from US EPA 2015).

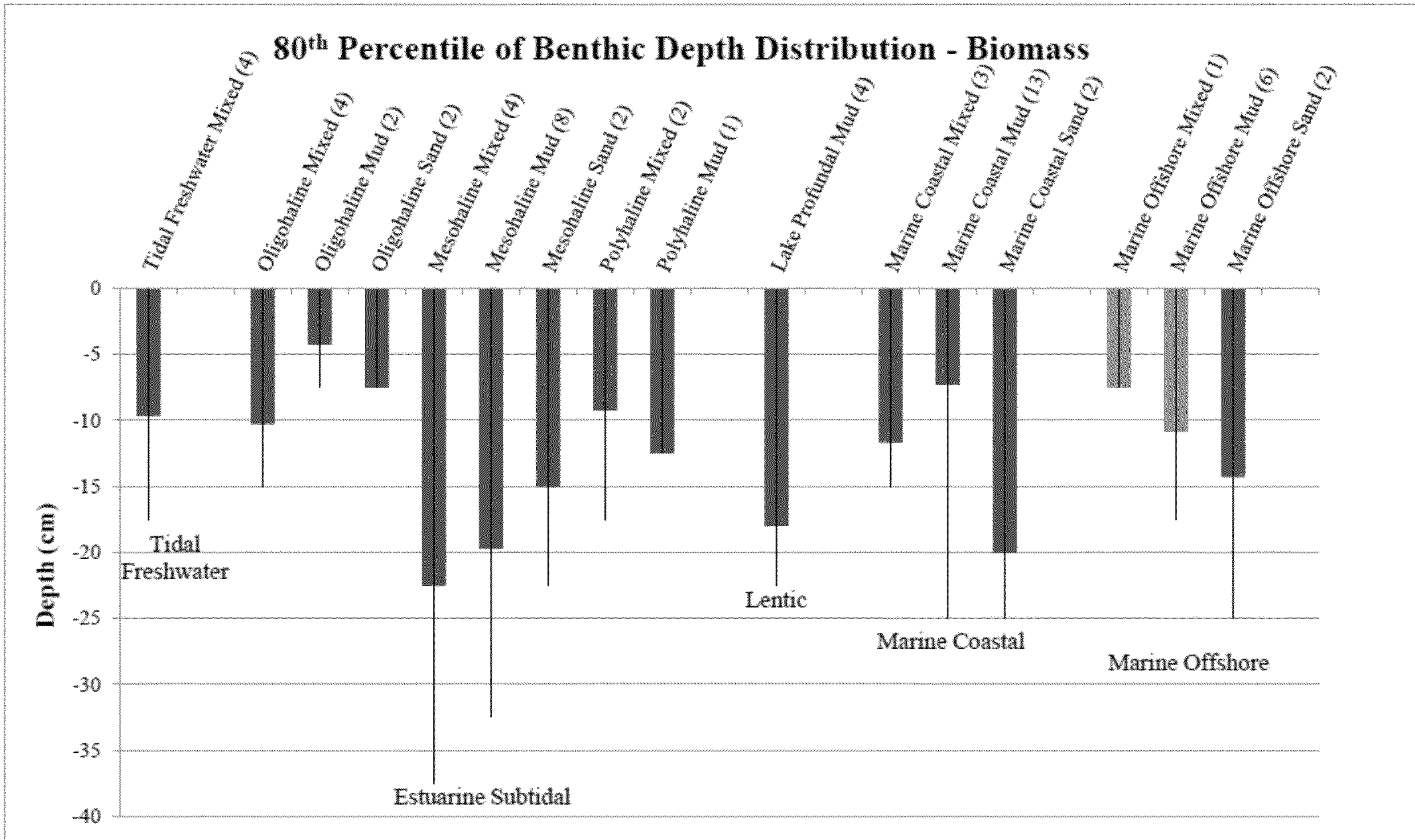

Figure 4. Mean 80th Percentile of Benthic Biomass Depth Distribution (+ Maximum 80th Percentile) in Various Habitats. Number of data sets in parentheses (the number of cores comprising data sets from each habitat type is noted in Table 4). Also see Table 4 for data locations.

Figure 3. Distribution by depth of benthic macroinvertebrates based on biomass (from US EPA 2015).

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Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit A

NITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
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NEW YORK, NEW YORK 10007 -1866

June 1, 2015

BY ELECTRONIC MAIL

Robert Law, Ph.D.
demaximis, inc.
186 Center Street, Suite 290
Clinton, New Jersey 08809

Re: Lower Passaic River Study Area, 17-Mile RI/FS
Benthic Community Exposure Depth

Dear Dr. Law:

On February 6, 2015, EPA met with the Cooperating Parties Group (CPG) to discuss their proposal to use 2 centimeters (cm) as the benthic community exposure depth in the Lower Passaic River Study Area (LPRSA). It is EPA's understanding that the CPG wants to use contaminant concentration simulation results averaged over this depth interval in the bioaccumulation model being developed by the CPG to predict future contaminant concentrations in biota post-remediation.

The CPG's proposal is based on their conclusion that the feeding zone for biota in the LPRSA is primarily limited to only the top 2 cm of contaminated sediment. To support this position, the CPG relied primarily on a Sediment Profile Imaging (SPI) Survey prepared by Germano & Associates, Inc. in 2005, particularly the redox potential discontinuity results from this survey (which show the depth of the aerobic layer), as well as benthic community data from the remedial investigation (RI) and relevant physical characteristics of the river such as organic carbon levels and dissolved oxygen concentrations.

EPA has reviewed the material presented by the CPG as well as additional material germane to their proposal. Although varying depths of benthic community exposure less than 15 cm may be appropriate for parts of the LPRSA, we do not support the use of a zone as shallow as 2 cm. Further, modeling contaminant concentrations in a zone with minimal empirical data will not yield accurate predictions. It is EPA's position that the existing RI data from the top 6 inches (approximately 15 cm) of sediment, and model concentration simulation results for this depth interval, should be used to represent contaminant concentrations for this parameter. That said, EPA is willing to discuss with the CPG their collection of new SPI data to more accurately determine the benthic community exposure depth for the LPRSA followed by the conduct of additional sediment sampling from appropriate depths, as identified during the new SPI survey.

EPA has come to this conclusion for several reasons:

a. Surface sediment sampling of the LPRSA has been performed in a number of phases over many years, with an agreed upon data use objective that a composited sample from the top 15 cm is representative of surface sediment concentrations across the entire sample depth. The top 2 cm of sediment is a very thin layer that is subject to constant change due to erosion, deposition and other factors. By contrast, a 15 cm composite, which is still a relatively thin surface layer, accounts for this variability and is a reasonable representation of the surface concentration at any point in time.

b. A review of the limited dataset of finely segmented cores with contaminant concentrations from depths of less than 15 cm shows significant variability: sometimes the surface concentrations are higher than concentrations averaged over the top 15 cm and sometimes they are lower. If these data suggest anything, it is that a 15 cm composite reasonably represents concentrations at shallower depths.

c. The existing dataset of finely segmented cores does not provide a reliable basis from which to model future concentrations in sediment. The contaminant fate and transport model has been calibrated using 15 cm data, and while there is uncertainty associated with any future projections, predicting concentrations over a significantly shallower and thinner horizon than the model is calibrated to would add unquantifiable uncertainty to the future projections.

d. The resolution of the existing bathymetry change dataset is significantly greater than 2 cm, due to factors including instrument accuracy and changes in surface sediment density (i.e., reflectiveness). The sediment transport model has been calibrated using the bathymetry change dataset, the accuracy of which is a direct function of the uncertainties of the individual bathymetry datasets, which means that the model cannot reliably predict bed elevation changes at scales as small as 2 cm. Since the contaminant fate and transport model's predictions of contaminant concentrations are driven by bed characteristics passed to it by the sediment transport model, this inability to reliably predict bed elevation changes at 2 cm scales would further add to the uncertainty in the predicted contaminant concentrations in the 2 cm layer.

For the reasons described above, EPA has concluded that use of the average model results from the 15 cm horizon, consistent with the RI data, is most appropriate to represent contaminant concentrations in the benthic community exposure zone for use in the bioaccumulation model for the 17 Mile RI/FS.

Please let me know if you have any questions.

Sincerely,

Stephanie Vaughn, Project Manager
LPRSA 17-Mile RI/FS

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit B

de maximis, inc.

186 Center Street
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(908) 735-9315
(908) 735-2132 FAX

June 12, 2015

Stephanie Vaughn
17-mile LPRSA RI/FS Remedial Project Manager
U.S. Environmental Protection Agency, Region 2
290 Broadway
New York, NY 10007-1866

Via Electronic Delivery

Re: **Invocation of Dispute Resolution - Benthic Community Exposure Depth -*Lower Passaic River Study Area (LPRSA) Region 2's June 1, 2015 Letter — May 2007 Administrative Agreement and Order on Consent for Remedial Investigation/Feasibility Study – CERCLA Docket No. 02-2007-2009 (AOC)***

Dear Ms. Vaughn:

This letter responds to the USEPA Region 2's (Region 2) June 1, 2015 letter (Region's June 1 Letter) to the Cooperating Parties Group (CPG) and seeks dispute resolution of the conclusion regarding benthic community exposure depth.

The Region's June 1 Letter provides: *"EPA has concluded that use of the average model results from the 15 cm horizon, consistent with the RI data, is most appropriate to represent contaminant concentrations in the benthic community exposure zone for use in the bioaccumulation model for the 17 Mile RI/FS"*. The CPG was disappointed by both the tenor and lack of support for the assertions contained in Region 2's letter. Region 2's response largely relies on an invocation of uncertainty; it does not comport with a four-month period of deliberation on such a significant matter as the exposure of the LPR biota to contamination, and is contradicted by data and Region 2's own modeling.

Region 2's conclusion is based on a series of unsupported assertions made in the EPA June 1 Letter including:

- *"...we do not support the use of a zone as shallow as 2 cm."*
- *"Modeling contaminant concentrations in a zone without empirical data will not yield accurate predictions."*
- *"... a 15 cm composite reasonably represents concentrations at shallower depths."*
- *"... predicting concentrations over a significantly shallower and thinner horizon than [the 15 cm interval that] the model is calibrated to would add unquantifiable uncertainty to the future projections."*
- *"... this inability to reliably predict bed elevation changes at 2 cm scales would further add to the uncertainty in the predicted contaminant concentrations in the 2 cm layer."*

These assertions lack scientific support and are contradicted by data and Region 2's own modeling used to support its April 2014 8-mile FFS-RI and Proposed Plan. The FFS model reflects that:

- The top 15 cm average is no less sensitive to inaccuracies in erosion/deposition than the 2 cm average;
- The computed vertical profiles indicate the 15 cm average is a poor representation of concentrations at shallower depths; and
- The 2 cm average is constrained by data because the model must predict reasonable water column concentrations that are largely determined by concentrations in the top few cm of the sediment bed.

Moreover, the Region's assertions are self-contradictory. For example, the following two statements are made in the same paragraph: "*The top 2 cm of sediment is a very thin layer that is subject to constant change ...;*" and "*a 15 cm composite ... is a reasonable representation of the surface concentration at any point in time*".

In addition, the Region's letter fails to address the point of the CPG's February 6, 2015 presentation and discussion with Region 2 and USEPA Headquarters representatives. The CPG has used existing site-specific ecological and biological data to draw conclusions regarding the transfer of chemicals in the food chain within the LPRSA. These observations are based on existing data collected under Region 2-approved QAPPs regarding the benthic community and fish community within the LPRSA. The CPG's conclusions are also based on sound ecological principles from decades of foundational benthic ecological work on community structure, function, and behavior.

The CPG's interpretation, that the exposure zone for most benthic invertebrates is primarily limited to the upper centimeters of sediment, is based on site-specific data, which provide multiple lines of evidence that fully support the CPG's conclusions. These LPRSA data also include the survey of the lower 15 miles of the river using Sediment Profile Imaging technology conducted by Region 2's and the Partner Agencies' contractor (Germano 2005). Importantly, Region 2's letter does not rebut the CPG's conclusion on the benthic community exposure zone because it cannot; rather it simply refers to "*additional material germane to their proposal*" as the basis for rejecting the multiple lines of evidence provided by site-specific data. Noteworthy, is the lack of reference to and discussion by the Region with regard to its primary line of evidence (*Burial and Burrowing Depth of Infaunal Organisms from the Passaic River, New Jersey* prepared by Region 2's consultant Robert S. Prezant, Ph.D. in May 2014) for deeper exposure depths and provided to the CPG earlier this year.

Furthermore, given Region 2's assertions regarding uncertainty, its offer "*...to discuss with the CPG their collection of new SPI data to more accurately determine the benthic community exposure depth for the LPRSA followed by the conduct of additional sediment sampling from appropriate depths, as identified during the new SPI survey*" seems disingenuous. That is, even if such data were collected, it would not change the Region's conclusions as additional empirical data on benthic community exposure depth and sediment chemistry are unlikely to adequately address the uncertainty factors alleged in Region 2's June 1 letter. Further, Region 2 is fully aware that this work could not be completed in a timely manner and would require at least a year for planning, conducting the work, reporting, Agency review, and reaching agreement on exposure depth(s).

In sum, Region 2's decision regarding benthic exposure depth lacks technical merit and is not being based on either sound science or site-specific data. Unfortunately, this determination seems consistent with a larger pattern by the Region of ignoring site-specific data (including its own) and refusing to engage in fulsome discussions on the total RI data set that Region 2 directed the CPG to collect at a cost of more than $100 MM over the last 8 years. As such, the CPG objects to the finding presented in the Region's June 1 Letter and hereby invokes dispute resolution pursuant to Section XV, paragraph 64 of the LPRSA AOC.

The CPG requests that Region 2 include this letter into the Administrative Record for the 17-mile LPRSA operable unit of the Diamond Alkali Superfund Site.

Please contact Bill Potter or me with any questions or comments.

Very truly yours,
de maximis, inc.

Robert H. Law, PhD
CPG Project Coordinator

cc: Ray Basso, EPA Region 2
Walter Mugdan, EPA Region 2
Sarah Flanagan, EPA Region 2
James Woolford, EPA HQ
Steve Ells, EPA HQ
CPG Members
William Hyatt, CPG Coordinating Counsel
Willard Potter, CPG Project Coordinator

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit C

NITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
290 BROADWAY
NEW YORK, NEW YORK 10007 -1866

June 25, 2015

BY ELECTRONIC MAIL

Robert Law, Ph.D.
demaximis, inc.
186 Center Street, Suite 290
Clinton, New Jersey 08809

Re: Notice of Dispute Resolution Pursuant to Dispute Resolution Provisions of Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

Dear Dr. Law:

The U.S. Environmental Protection Agency (EPA) is in receipt of your letter dated June 12, 2015, invoking dispute resolution under the above-referenced Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study (RI/FS Settlement Agreement) with respect to EPA's June 1, 2015 letter concluding that use of the average model results from the 15 centimeter (cm) depth horizon, consistent with the RI data, is most appropriate to represent contaminant concentrations in the benthic community exposure zone for use in the bioaccumulation model for the 17 Mile RI/FS.

The CPG argues that EPA's conclusion is based on a series of "unsupported" and "self-contradictory" assertions and that the region is ignoring site-specific data. The CPG further asserts that EPA's offer to discuss the conduct of an additional Sediment Profile Imaging (SPI) survey and possibly additional sediment sampling "seems disingenuous." EPA disagrees with the CPG's assertions and specifically with the CPG's contention that the existing SPI data supports a 2 cm depth of exposure.

EPA accepts your notice letter as having triggered the RI/FS Settlement Agreement dispute resolution process and is willing to discuss these issues with the CPG. While your June 12, 2015 letter generally describes the CPG's objections to the EPA June 1, 2015 letter, to engage in meaningful discussions during the Negotiation Period pursuant to Paragraph 64 of the RI/FS Settlement Agreement, EPA requires the Settling Parties to submit a detailed written statement of their objections, particularly to support the three bulleted assertions at the top of Page 2 of the letter.

Once we have received a detailed written statement as described above, EPA will work with the Settling Parties to attempt to resolve the dispute, including by scheduling a meeting if it appears that this would be productive. In order for EPA to evaluate whether an extension of the 31 day

Negotiation Period is called for, please advise when the CPG will be able to submit the more detailed written statement.

Please let me know if you have any questions.

Sincerely,

Stephanie Vaughn, Project Manager
LPRSA 17-Mile RI/FS

cc: W. Mugdan, ERRD
E. Schaaf, ORC
R. Basso, ERRD
S. Flanagan, ORC
W. Hyatt, CPG

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit D

de maximis, inc.

186 Center Street
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Clinton, NJ 08809
(908) 735-9315
(908) 735-2132 FAX

July 2, 2015

Stephanie Vaughn
17-mile LPRSA RI/FS Remedial Project Manager
U.S. Environmental Protection Agency, Region 2
290 Broadway
New York, NY 10007-1866

Via Electronic Delivery

Re: Notice of Dispute Resolution - Benthic Community Exposure Depth -Lower Passaic River Study Area (LPRSA) Region 2's June 25, 2015 Letter — May 2007 Administrative Agreement and Order on Consent for Remedial Investigation/Feasibility Study – CERCLA Docket No. 02-2007-2009 (AOC)

Dear Ms. Vaughn:

This letter responds to the USEPA Region 2's June 25, 2015 letter to the Cooperating Parties Group (CPG), which accepts the CPG's June 12, 2015 letter as having triggered dispute resolution of the Region's conclusion regarding benthic community exposure depth and requests that the CPG advise when it will be able to submit a more detailed written statement of its objections.

In order for the CPG to provide a date for delivery of its written statement, the CPG requests that the Region provide the *"additional material"* it reviewed in connection with the CPG's proposal to use 2 centimeters as the benthic community exposure depth in the LPRSA. Specifically, Region 2's June 1, 2015 letter states *"EPA has reviewed the material presented by the CPG as well as additional material germane to their proposal"*. The CPG should have the opportunity to review and respond to any and all materials that the Region has relied upon to draw its conclusion(s) on this critical issue. Following receipt of this material, the CPG will promptly provide a date for delivery of its detailed statement.

The CPG also notes that we disagree with the implication in the Region's June 25 letter that the CPG is relying solely on the 2005 Sediment Profile Imaging (SPI) study prepared by contractors of Region 2 and its Partner Agencies to support the CPG's conclusions on exposure depth. As stated in the CPG's June 12 letter, the CPG has reviewed and considered all available site-specific data, as well as the larger ecological literature, to develop an appropriate exposure depth for the 17-mile LPRSA. The CPG's February 2015 presentation provided multiple lines of evidence that clearly support the use of an exposure depth less than 15 cm.

The CPG requests that Region 2 include this letter into the Administrative Record for the 17-mile LPRSA Operable Unit of the Diamond Alkali Superfund Site.

Please contact Bill Potter or me with any questions or comments.

Very truly yours,
de maximis, inc.

Robert H. Law, Ph.D
CPG Project Coordinator

cc: Ray Basso, EPA Region 2
Walter Mugdan, EPA Region 2
Sarah Flanagan, EPA Region 2
James Woolford, EPA HQ
Steve Ells, EPA HQ
CPG Members
William Hyatt, CPG Coordinating Counsel
Willard Potter, CPG Project Coordinator

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit E

NITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
290 BROADWAY
NEW YORK, NEW YORK 10007 -1866

July 9, 2015

BY ELECTRONIC MAIL

Robert Law, Ph.D.
demaximis, inc.
186 Center Street, Suite 290
Clinton, New Jersey 08809

Re: Dispute Resolution Pursuant to Dispute Resolution Provisions of Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

Dear Dr. Law:

The U.S. Environmental Protection Agency (EPA) is in receipt of your letter dated July 2, 2015, requesting material relied on by EPA to draw its conclusion that use of data from the 15 centimeter (cm) horizon is appropriate to represent contaminant concentrations in the benthic community exposure zone. On June 12, 2015, the Cooperating Parties Group (CPG) invoked dispute resolution over this issue.

The attached document responds directly to the CPG's June 12, 2015 letter. It also provides the additional material/analysis requested in your July 2, 2015 letter. In addition, contrary to your July 2, 2015 letter, please note that EPA never stated nor implied that the CPG relied solely on the 2005 Sediment Profile Imaging survey conducted by the USACE and NJDOT to support its conclusions on exposure depth. While EPA agrees that the CPG presented multiple lines of evidence to support its position, EPA does not agree that the SPI data and other evidence clearly support an exposure depth of 2 cm.

Please let EPA know when the CPG intends to deliver its written statement as requested by EPA in its June 25, 2015 letter, and feel free to contact me with any questions.

Sincerely yours,

Stephanie Vaughn, Project Manager
LPRSA 17-Mile RI/FS

Attachment

cc: W. Mugdan, ERRD
R. Basso, ERRD
S. Flanagan, ORC
W. Hyatt, CPG

Attachment

a. Review of 2005 SPI Data (CPG 6/12/2015 letter, Page 1, Bullet 1 and Page 2, Paragraphs 3 and 4)

To support its position that the benthic community exposure depth in the LPRSA should be 2 cm, the CPG relies in large part upon a Sediment Profile Imaging (SPI) survey conducted in 2005. Note that the survey was conducted 10 years ago by the USACE and NJDOT to support their restoration planning, not by EPA as part of the Lower Passaic River Study Area (LPRSA) RI/FS, and the purpose of the survey was not to determine the biological active zone or depth of exposure for the LPRSA.

Notwithstanding the above, EPA and the CPG agree that the 2005 survey found a shallow anoxic zone, with low Redox Potential Discontinuity (RPD). However, where EPA and the CPG disagree is that the depth of the RPD correlates with the limit of the BAZ. Figure 1 shows all of the feeding void depths found during the survey plotted against the measured depth of the RPD. While the RPD remains below 4 cm at all locations, the feeding void depth varies more widely, up to nearly 15 cm. No correlation between RPD and feeding void depth is shown. In fact, as is shown in Figure 2, only one of the feeding voids found went down to a maximum depth of less than 2 cm.

b. Review of Finely Segmented Core Data (CPG 6/12/2015 letter, Page 1, Bullets 2, 3 and 4 and Page 2, Bullets 1, 2 and 3)

Between 2005 and 2013, samples were collected from the top 6 inches of sediment at approximately 500 locations in the LPRSA (from Newark Bay to Dundee Dam) to support the 17-mile RI/FS. Sediment was collected from the top 2 cm at only 8 locations. Figures 3 and 4 show the results for 2,3,7,8-TCDD at these 8 locations. For each location, Figure 3 shows the detected concentration at each of the finely segmented core depths in blue, the 15 cm average concentration in pink and the 2 cm to 15 cm ratio of concentrations in brown. Figure 4 shows a cumulative distribution plot of the ratios.

As the figures show, the concentration of 2,3,7,8-TCDD averaged over 15 cm compared to the concentration at the top 2 cm is highly variable. While this is not a statistically valid dataset from which to draw conclusions about 2 cm concentrations across the river, the results do suggest that there are insufficient data from the top 2 cm to evaluate model performance.

Despite the fact that the limited data set shows high variability, based on the modeling files provided to EPA in December 2014, the CPGs modeled predictions over 2 cm are consistently lower than those predicted over 15 cm on a reach averaged basis and over the vast majority of individual grid cells in the LPRSA. Over the duration of the 1995-2013 calibration period, the CPG's model predictions of 2,3,7,8-TCDD in the top 2 cm average less than half of the concentration in the top 15 cm. Given the variability in the limited 2 cm data set, EPA does not have confidence in these modeling results; they would need to be verified through the collection of additional data.

EPA disagrees with the CPG's assertion that the water column contaminant data provide a constraint on the 2 cm bed concentrations, because the water column concentrations are controlled by contaminant concentrations in the fluff layer and the CPG's model includes a parameter to control the transfer of contaminants between the upper layer of the bed and the fluff layer. The combination of the transfer parameter and contaminant concentrations in the upper layer of the bed (below the fluff layer) control contaminant flux to the water column. This provides a non-unique link between the water column and the bed below the fluff layer. While alternate combinations of bed concentrations and transfer parameters could reproduce water column contaminants equally well, the bioaccumulation model would be affected by these alternate choices.

c. Review of Bathymetry Data (CPG 6/12/2015 letter, Page 1, Bullet 5)

The existing bathymetry change dataset cannot resolve changes as finely as 2 cm, due to factors including instrument accuracy and changes in surface sediment density (i.e., reflectiveness). The sediment transport model has been calibrated using the bathymetry change dataset, the accuracy of which is a direct function of the uncertainties of the individual bathymetry datasets, which means that the model cannot reliably predict bed elevation changes at scales as small as 2 cm. This means that there is no way to determine if the solids calculated to be present in the top 2 cm are, in fact, present in a particular grid cell or present but buried by subsequent deposition. Since the contaminant fate and transport model's predictions of contaminant concentrations are driven by bed characteristics passed to it by the sediment transport model, this inability to reliably predict bed elevation changes at 2 cm scales would further add to the uncertainty in the predicted contaminant concentrations in the 2 cm layer. The contaminant fate and transport model cannot be expected to produce reliable estimates of contaminants present in the top 2 cm if the sediment transport model cannot produce reliable estimates of the solids transport at this high level of vertical resolution.

d. Offer to Discuss Collection of Additional Data (CPG 6/12/2015 letter, Page 2, Paragraphs 2 and 5)

As is stated in our June 1, 2015 letter, even though EPA concludes that average model results from the 15 cm horizon reasonably represent contaminant concentrations in the benthic community exposure zone, EPA agrees that varying depths of benthic community exposure zone less than 15 cm may be appropriate for parts of the LPRSA. However, the actual depth that is appropriate under current conditions would need to be quantified. An additional SPI survey designed specifically to answer this question could help determine the actual depth, or depths (if they are found to vary over the length of the river). Then, depending on the results, the decision could be made as to whether additional sediment sampling and/or surveys are warranted. If warranted, more than one round of sampling would be needed to determine the variability of the shallow dataset over time.

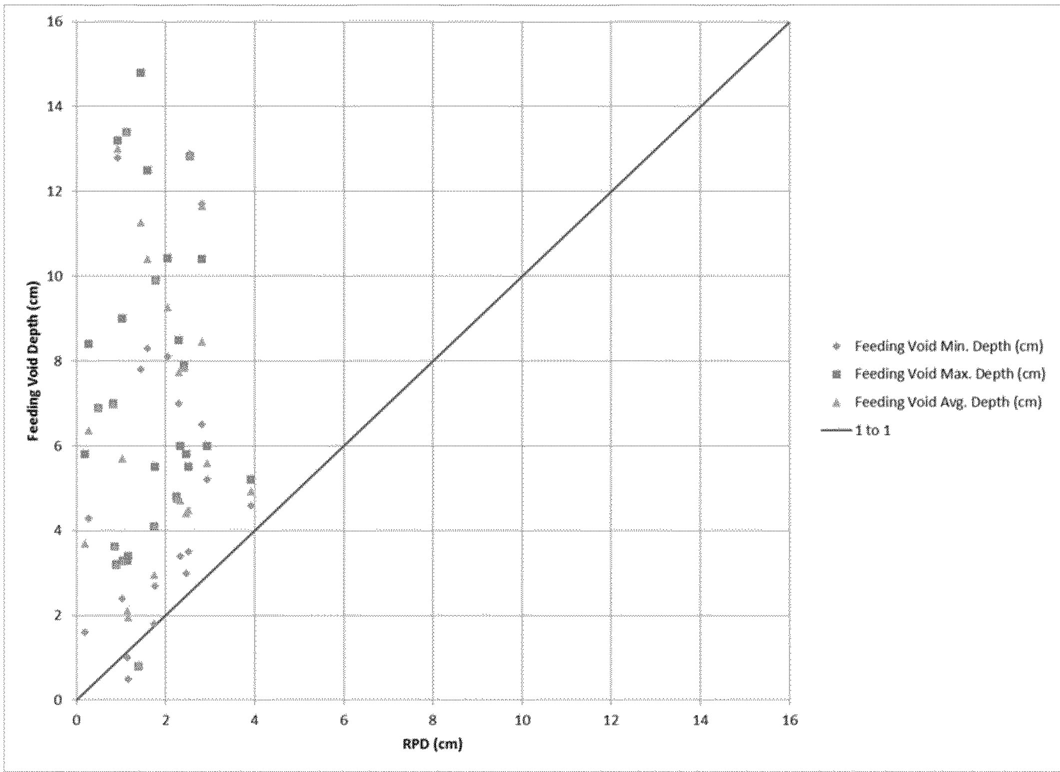


Figure 1 – Feeding Void Depth versus RPD based on results from 2005 SPI Survey conducted by Germano and Associates.

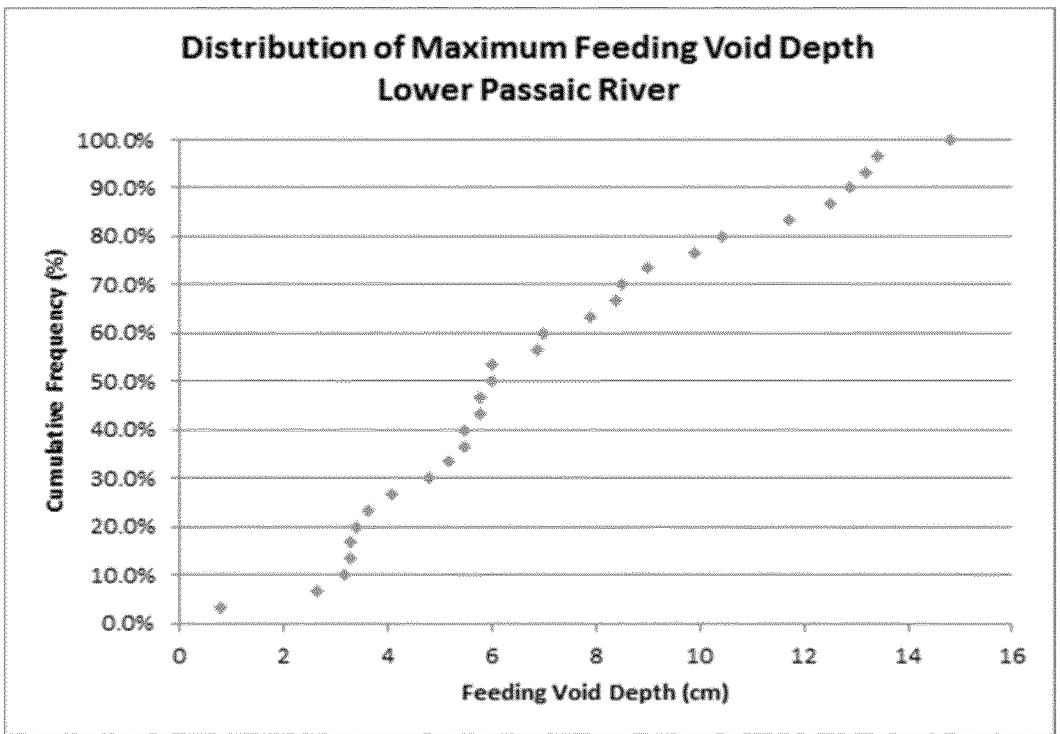
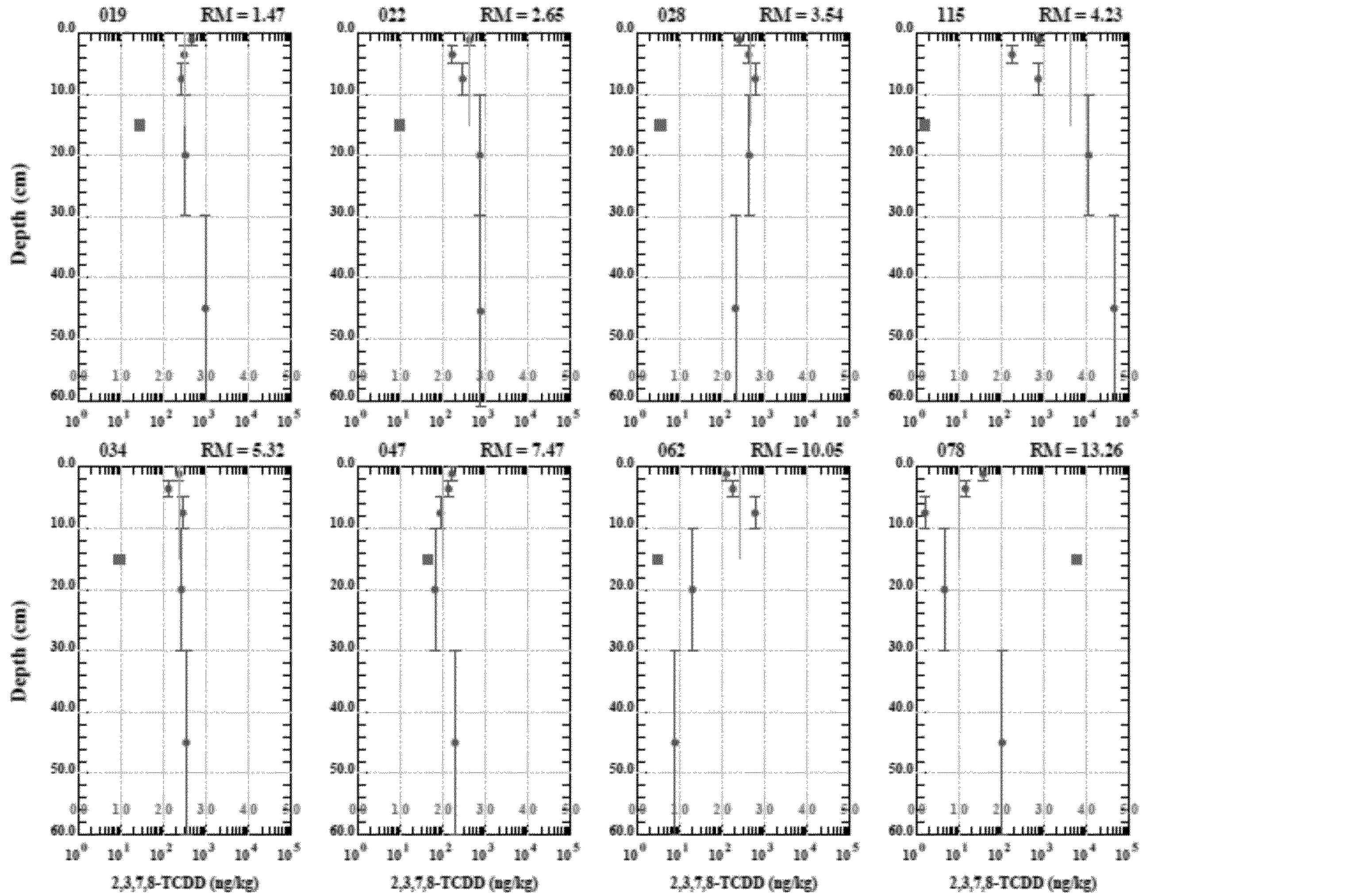
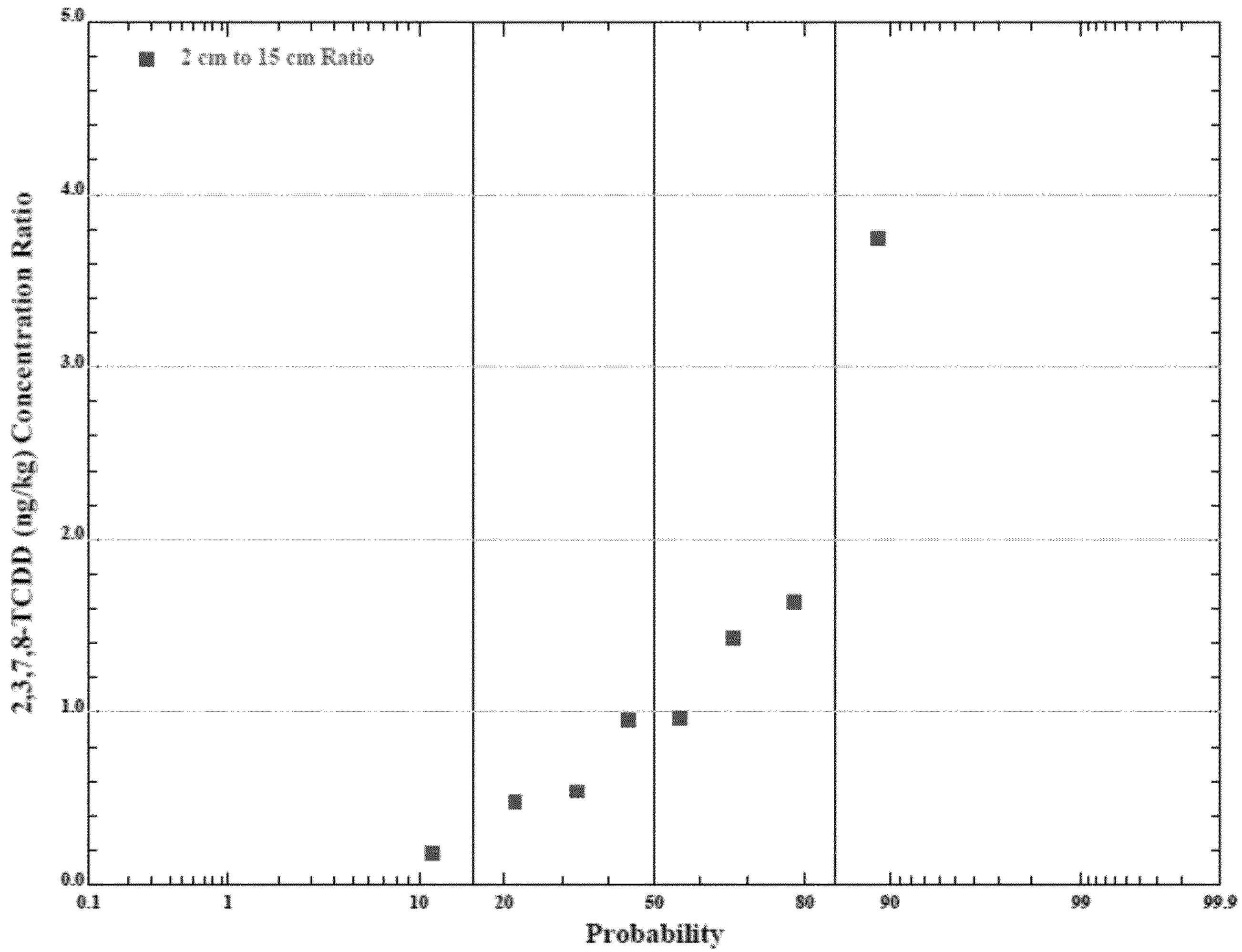


Figure 2 – Cumulative frequency distribution of feeding Void Depth, based on results from 2005 SPI Survey conducted by Germano and Associates.



2,3,7,8-TCDD (ng/kg) Vertial Profile in 2008 CPG Finely Segmented Cores

Figure 3



2 cm to 15 cm Ratio
2,3,7,8-TCDD (ng/kg) Concentration Ratio
5.0
4.0
3.0
2.0
1.0
0.0
0.1
1
10
20
50
80
90
99
99.9
Probability

Figure 4

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit F

From: Robert Law [mailto:rlaw@demaximis.com]
Sent: Thursday, September 17, 2015 10:54 AM
To: Vaughn, Stephanie <Vaughn.Stephanie@epa.gov>
Cc: Willard Potter <otto@demaximis.com>; Lisa Saban <LisaS@windwardenv.com>; Mike Johns <MikeJ@windwardenv.com>
Subject: Exposure Zone (EZ) QAPP Work Sheets

Stephanie:

The CPG is providing the attached zip file containing QAPP Work Sheets 9, 10, 11, 14 and 17 plus figures and tables in order to further discussion of initiating a sampling program to determine an appropriate and site-specific exposure depth(s) for the LPRSA starting in October.

During my absence between September 18 and September 29 - please contact Bill Potter if the Region has questions or comments and wishes to continue discussions.

Thank you.

R/
Rob

Robert Law, Ph.D.
de maximis, inc.
rlaw@demaximis.com
Voice: 908-735-9315
Fax: 908-735-2132

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit G

de maximis, inc.

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(908) 735-2132 FAX

October 16, 2015

Stephanie Vaughn
Ray Basso
17-mile LPRSA RI/FS Remedial Project Manager
U.S. Environmental Protection Agency, Region 2
290 Broadway
New York, NY 10007-1866

Via Electronic Delivery

Re: ***Lower Passaic River Study Area (LPRSA) Exposure Zone Dispute Resolution – Proposed Sampling Program – May 2007 Administrative Agreement and Order on Consent for Remedial Investigation/Feasibility Study – CERCLA Docket No. 02-2007-2009 (AOC)***

Dear Ms. Vaughn and Mr. Basso:

The Lower Passiac River Cooperating Parties Group (CPG) wanted to provide a follow-up to the telephone conversation between CPG and Region 2 representatives on Thursday, October 8, 2015 concerning several issues, including the CPG proposal for additional exposure zone sampling and the Region's BHHRA and BERA RTC responses. This response is specific to the additional exposure zone sampling proposal.

As you know, the CPG and Region 2 are currently engaged in formal dispute resolution concerning the bioactive exposure zone since it is an important subject which will impact completion of several essential elements to the 17-mile RI/FS of the Lower Passaic River. As a part of our discussions in this regard, Region 2 was the party that first suggested in its June 1, 2015 letter that the CPG develop a plan to collect additional data to help resolve disputed issues concerning the bioactive exposure zone and the location of benthic organisms that are potential food sources for fish. The CPG spent considerable time throughout the summer developing a responsive sampling program to obtain additional data. The CPG and Region conducted a call on August 26, 2015 to discuss the sampling program. The CPG delivered key QAPP worksheets for Region 2's review and further discussions on September 17, 2015. One of the purposes for October 8 call was to determine when Region 2 comments would be received such that CPG contractors could immediately finalize the Exposure Zone QAPP Addendum, begin to undertake the fieldwork and gather the data and samples before weather conditions make it impossible to initiate the sampling this year. It should be noted that similar data on benthic organisms were originally collected in the Fall of 2009.

Based upon our conversation on October 8, the CPG understands that Region 2 expects to provide a high level summary of concerns and issues by letter sometime within 2 weeks of the call. However, the Region was not able to elaborate or provide any specific details on potential concerns or comments of the Region or their partner agencies during our call. The only details provided were that the Region's representatives thought it would take six months of planning and as much as three years to complete the sampling process without any scientific justification for that conclusion. Moreover, the CPG understands that the Region does not believe that it can fully comment on the QAPP Addendum and associated data needs until it has completed its review of the CPG's bioaccumulation model which will not be completed for a number of months.

The CPG does not understand Region 2's response and current position. The Region proposed collecting additional data in its June 2015 letter, but did not identify its review of the bioaccumulation model as a major prerequisite or impediment to developing and implementing a sampling program. Only after the CPG provided details on a sampling program did the Region identify the need for a full review of the bioaccumulation model. The Region's June 1 letter did not identify the need for Partner Agency participation in developing a sampling program and the now the Region has decided to include them in the planning. The CPG has proposed a technically sound sampling and is prepared to submit a full QAPP Addendum, including the Region's specific recommendation to conduct a new sediment profile imaging survey. Although the CPG does not believe it is necessary to collect additional sediment chemistry as suggested by the Region since direct measurement of benthic invertebrate tissue chemical concentration is part of the CPG's proposed work. Nonetheless, CPG representatives stated on August 26 that they would discuss the possibility of including some sediment chemistry sampling. The CPG has worked quickly and efficiently to develop a sampling program to gather additional data that will help address the issues raised by Region 2 and presumably the partner agencies.

There is no justification for Region's inability to provide a timely and complete technical response and the implication that this needs to be a long drawn out, multi-year process calls into question Region 2's sincerity in attempting to resolve the dispute and more importantly its commitment to allowing the CPG to complete its mandated RI/FS which should govern any remedial options on the river. This is another in many recent instances of lack of or a delay in a technical response from the Region. It is apparent from the response that Region 2 will make it impossible for the CPG to conduct the sampling this fall, creating a lengthy set back in addressing this important issue. It is also apparent that Region 2 has little interest in developing key information that will help resolve the disputed issues.

The CPG ask that the Region expedite the response to our proposal so that CPG can evaluate it in connection with our efforts to quickly and appropriately finalize the RI/FS.

The CPG requests that Region 2 include this letter into the Administrative Records for the 17-mile LPRSA operable unit of the Diamond Alkali Superfund Site and the Region's 8-mile FFS and Proposed Plan.

Please contact Bill Potter or me with any questions or comments.

Very truly yours,

de maximis, inc.

Robert H. Law, PhD
CPG Project Coordinator

cc: Walter Mugdan, EPA Region 2
Sarah Flanagan, EPA Region 2
CPG Members
William Hyatt, CPG Coordinating Counsel
Willard Potter, CPG Project Coordinator

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit H

NITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
290 BROADWAY
NEW YORK, NEW YORK 10007 -1866

October 23, 2015

BY ELECTRONIC MAIL

Robert Law, Ph.D.
demaximis, inc.
186 Center Street, Suite 290
Clinton, New Jersey 08809

Re: Lower Passaic River Study Area, 17-Mile RI/FS
Benthic Community Exposure Depth

Dear Dr. Law:

On June 1, 2015, the U.S. Environmental Protection Agency (EPA) sent a letter to the Cooperating Parties Group (CPG) in response to its proposal to use 2 centimeters (cm) as the benthic community exposure depth for the Lower Passaic River Study Area (LPRSA). In that letter, EPA explained our conclusion that the use of average model results from the 15 cm horizon is most appropriate to represent contaminant concentrations in the benthic community exposure zone for use in the bioaccumulation model for the 17-mile Remedial Investigation/Feasibility Study (RI/FS). EPA also acknowledged in that letter that varying depths of benthic community exposure less than 15 cm may be appropriate for parts of the LPRSA and stated that we would be willing to discuss with the CPG additional studies that could be conducted to evaluate this possibility.

On June 12, 2015, the CPG responded to EPA's June 1, 2015 letter, invoking dispute resolution with respect to EPA's conclusion that existing RI data from the top 6 inches of sediment, and model concentration simulation results for this depth interval, should be used to represent contaminant concentrations for this parameter.

EPA responded to the June 12, 2015 notice by letter dated June 25, 2015, asking the CPG for a more detailed written statement of objections and indicating that EPA would work with the CPG to attempt to resolve the dispute. EPA also indicated that on receipt of the detailed written statement, EPA could determine whether to extend the Negotiation Period called for in Paragraph 64 of the Administrative Settlement Agreement and Order on Consent (AOC) for the RI/FS.

The CPG responded on July 2, 2015, not with a detailed statement, but with a request for additional information reviewed by EPA in preparing its June 1, 2015 letter. On July 9, 2015, EPA provided additional information and again requested a detailed statement. To date, the CPG has not provided a detailed statement. However, EPA has allowed the Negotiation Period to continue, and this letter confirms that we remain in this extended Negotiation Period.

On August 18, 2015, you contacted me to initiate a discussion regarding additional sampling, as suggested by EPA in its June 1, 2015 letter, and on August 26, 2015 the CPG presented its proposed additional sampling program to EPA via teleconference. The CPG requested that we let it know quickly if EPA could support the program as described or if we had significant reservations. Responding to this request, EPA informed the CPG on September 1, 2015 that a more robust program that includes sediment sampling would need to be developed if EPA were to support it.

The CPG then asked EPA to review draft Quality Assurance Project Plan (QAPP) worksheets it was developing for this work prior to deciding whether the scope of the program is sufficient. The CPG submitted those worksheets on September 17, 2015, and EPA has now reviewed the worksheets in sufficient detail to make that determination. Ray Basso and I discussed our feedback with you on October 8, 2015, and you asked that we provide our major concerns in writing. These are laid out below.

1. A much more robust, multi-season, possibly multi-tidal sampling program is needed. At a minimum, a fall and spring event would be needed, and full seasonal coverage is preferred. As you know, there is a high degree of variability associated with these data and any sampling conducted must be able to reduce, or at least determine the bounds on, this variability. From a biological perspective, seasonal differences include, but are not limited to, spawning, storage of food reserves, release of larvae, vertical and horizontal migration, and ultimately larval or juvenile settlement. In addition, as evidenced by our recent experience at RM 10.9, the surface sediment layer is subject to short-term deposition and remobilization and/or consolidation on a regular basis;

2. Sediment sampling must be part of the program. There are several Data Quality Objectives for the sediment sampling, including:

    a. Correlation of sediment concentrations with benthic invertebrate tissue concentrations, to determine if tissue concentrations are consistent with specific depth profiles. For example, if benthic invertebrates are collected from 2-4 cm and analyzed, but their concentrations do not correlate with the sediment concentrations from that same interval, this may indicate that they are becoming contaminated from another interval. Please keep in mind that some benthic, infaunal invertebrates can migrate vertically, so direct correlations between tissue and sediment concentrations must consider species in question and their behavior;

    b. Estimation of exposure to benthic invertebrates for intervals containing feeding voids but no benthic invertebrate tissue; and

    c. Provision of quantitative data for use in the models so that the bioaccumulation model and fate and transport model have data collected from similar profiles.

3. EPA is still completing its review of the bioaccumulation model, and on October 21, 2015 received additional information from the CPG it needs to complete the review. This highlights another concern that we will need to address going forward; the integration of the exposure depth sampling program with the development and approval of the bioaccumulation model.

EPA appreciates the effort the CPG put into developing this program, which includes the direct measurement of biomass data and benthic organism tissue concentrations. However, even with these important measurements, the program is not sufficient to resolve the unknowns that the program is attempting to answer. The question of where benthic organisms are feeding is a highly complex one in any water body, and trying to make this determination for use in future projections in a tidal estuary impacted by contamination is even more difficult. EPA suggested that additional studies could help resolve this issue, and we still think this is the case. However, we now understand that the study that would be needed to resolve the issue is much more complex than originally understood, and there is no guarantee that at the end of a multi-year program a clear answer would present itself. As such, EPA continues to support the use of results from the 15 cm horizon to represent concentrations in the benthic community exposure zone.

In its October 16, 2015 letter, the CPG questions EPA's basis for allowing for any Partner Agency review of the CPG's proposed sampling program. As the CPG is aware, the Partner Agencies are an integral part of the RI/FS process, and have been so since its inception; they are involved with all aspects of the RI/FS development and review, and this involvement does not need to be stated explicitly for each issue. The October 16 letter also expresses displeasure at the amount of time it has taken EPA to provide feedback on the proposed sampling program. Please note that, while apparently the CPG has been working on developing this program all summer, EPA did not become aware of the CPG's plan until late August, and did not receive anything formal to review until September 17th. As is noted above, EPA told the CPG on September 1st, prior to the submittal of the draft QAPP worksheets, that a more comprehensive program would be needed, and repeated this comment when we spoke on October 8th. EPA never affirmed that the CPG would be able to undertake the fieldwork this fall. Finally, as is stated in the previous paragraph, EPA disagrees that this issue should hold up completion of the RI/FS and continues to support the use of existing data.

As described above, EPA has informally extended the Negotiation Period for the dispute resolution invoked by the CPG on June 12, 2015. We are willing to continue this extension while we continue the ongoing discussions that EPA has already engaged in with the CPG on this topic. However, given that the CPG is now expressing deep dissatisfaction with this process, we question whether these discussions are achieving the intended purpose of resolving the disagreement between EPA and the CPG. Unless we hear from the CPG to the contrary, we are expecting to take the next steps needed to present this dispute to the Director of the Region 2 Emergency and Remedial Response Division.

We look forward to hearing from you.

Sincerely,

Stephanie Vaughn, Project Manager
LPRSA 17-Mile RI/FS

cc: R. Basso, EPA
W. Mugdan, EPA
S. Flanagan, EPA
W. Hyatt, CPG

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit I

de maximis, inc.

186 Center Street
Suite 290
Clinton, NJ 08809
(908) 735-9315
(908) 735-2132 FAX

November 13, 2015

Stephanie Vaughn
17-mile LPRSA RI/FS Remedial Project Manager
U.S. Environmental Protection Agency, Region 2
290 Broadway
New York, NY 10007-1866

Via Electronic Delivery

Re: ***Lower Passaic River Study Area (LPRSA)-Exposure Depth/Zone Dispute Resolution***
(1) Dispute Resolution Statement
(2) Response to Region 2's October 23, 2015 letter
May 2007 Administrative Agreement and Order on Consent for Remedial Investigation/Feasibility Study – CERCLA Docket No. 02-2007-2009 (AOC)

Dear Ms. Vaughn:

The Lower Passaic River Cooperating Parties Group (CPG) is delivering its (1) Dispute Resolution Statement as part of the CPG's June 12, 2015 invocation of dispute resolution pursuant to paragraph 64 of the May 2007 Administrative Order on Consent and (2) responding to USEPA Region 2's (Region 2) October 23, 2015 letter.

Region 2 has failed to provide any substantive and cogent basis for denying the use of an exposure zone as shallow as 2 cm. The Region's arguments have continued, throughout the nearly 2 years of this issue to be (1) generalized, (2) largely based on assertions of a technically unsupportable and vague allegation of "uncertainty", (3) a scientifically insupportable reliance on partial and/or incorrect information or (4) more recently, an assertion that data collection (which the Region initially invited) would take too long or be too complicated. This has been true since the dispute began with the Region's June 1, 2015 letter and continues with its recent letter on October 23, 2015. Additional hurdles have been presented with Region 2's positions:

- The Region's May 2014 expert paper prepared by a contractor to CDM-Smith was incomplete and severely flawed because it specifically cited maximum burrowing depths when the vast majority of benthic invertebrates were shown to reside within a few centimeters of the surface.
- The Region is either ignoring or contradicting the results of its own 2014 FFS model when it states that the model cannot reliably predict concentrations for intervals of less than 15 cm.
- The Region has inexplicably changed it positon on a 2 cm exposure zone as evidenced by its May 1993 OU 2 Scope of Work.

- The Region has been reluctant if not unwilling to meet with the CPG and have meaningful and substantive exchange on this matter – it has avoided meeting on this issue with the CPG since February 2015.

The CPG has prepared a Dispute Resolution Statement on this matter, as it relates to comments and assertions made by Region 2 in its June 1, 2015 letter and subsequent correspondence on the findings of the CPG regarding the exposure depth or zone (hereafter exposure zone or EZ) issue for the 17-mile Lower Passaic River Study Area (LPRSA). The issue of what is an appropriate exposure zone has been discussed at two meetings between Region 2 and the CPG in February 2014 and February 2015. Following the February 2014 meeting, the CPG provided additional information on the matter (including site specific data) at the request of Region 2 in a letter and attachments dated February 19, 2014. The Region did not provide a response to that letter and did not engage in further discussions with the CPG on this matter for a year - until February 2015. Nearly four months after the February 2015 meeting, Region 2 provided on June 1, 2015 its comments and assertions on the matter of a LPRSA exposure zone. In that letter, the Region suggested that additional sampling could be conducted to resolve the differences between the Region and CPG. Additional correspondence on this matter was received by the CPG by way of the Region's letters dated June 25, 2015 and July 9, 2015.

As a result of the Region's June 1, 2015 letter, the CPG invoked dispute resolution on June 12, 2015; this letter was acknowledged by the Region on June 25, 2015. The CPG sent a third letter on July 2, 2015 requesting the information that the Region had used to make its determinations; the Region responded to this request on July 9, 2015.

Additionally, on August 18 2015, CPG contacted the Region to discuss at the earliest opportunity the development of a sampling program that the Region invited in its previous correspondence. The CPG provided the Region an overview of a proposed sampling plan in advance of the August 26, 2015 teleconference. The CPG agreed to provide a more formal proposal in the form of draft Quality Assurance Project Plan (QAPP) worksheets and it was agreed that the Region and CPG would continue discussions. The CPG provided draft QAPP worksheets for a proposed sampling program on September 17, 2015 to support the development of site-specific exposure zone(s); no further response was received from the Region. On October 5, the CPG contacted the Region by email to inquire on the status of the CPG's proposed EZ sampling program. The Region and the CPG agreed to conduct a call on October 8; the CPG would characterize the call as cordial but generally uninformative on the part of Region 2 as to specific technical issues with the CPG's technical approach to developing site-specific exposure zone(s) other than the Region suggesting that the sampling program would take possibly 3 years and might be too complicated to implement and interpret. The CPG requested and the Region agreed to provide a "high-level" response outlining its concerns within 2 weeks. On October 16, the CPG sent a letter summarizing its continued concerns and justifiable frustration with the Region's unwillingness to conduct a meaningful and timely engagement with the CPG on this matter. The Region provided its promised high-level response on October 23 and responded to the CPG's October 16 letter as well.

In its October 23 letter, Region 2 provided response to the CPG's proposed EZ sampling program. There are two main elements to the comments from Region 2 that require response: (1) need to conduct a multi-season survey, and (2) the necessity of incorporating a sediment chemistry investigation into the sampling program. The following responses are provided:

- Multi-Seasonal Survey - Region 2 states that any sampling program should be multi-seasonal, with sampling conducted, at a minimum, in the spring and fall but with full seasonal coverage preferred. The justification provided by Region 2 is that there is "*a high degree of variability associated with these data*" so multiple sampling events is required. Region 2 stated the need for multiple sampling efforts to reduce, or at least determine, the bounds on this variability. The CPG is unclear as to what variability Region 2 is referring given that the LPRSA observations and data collected to date suggest a static benthic community that is seasonally unaffected. Specifically, seasonal benthic community data collected throughout the 17-mile LPRSA under Region oversight as part of the RI shows station-specific changes in abundance that are well within expected seasonal changes. More importantly, minimal changes in station-specific species composition have occurred throughout the season within the LPRSA, indicating the existence of stable benthic communities throughout the year. Given the existing significant data on the seasonal composition, the CPG considers a single survey sufficient to describe the vertical depth of members of the benthic community.

  Region 2 stated that it may require a multi-tidal sampling program. While very minor changes in vertical depth might occur with some benthic organisms that reside in intertidal sediment, the potential movements are at most millimeters and certainly not enough of a scale to justify a sampling program across tidal cycles, which would unnecessarily complicate the program and extend the schedule. The CPG requests any data or publications that Region 2 has relied on that support the need for a multi-tidal sampling program (i.e. indication of significant, tidally-induced movement of benthic organisms relevant to the data quality objective (DQO) of the proposed work).

  Finally, Region 2 lists a number of seasonal differences including spawning, storage of food reserves, release of larvae, and larval and juvenile settlement, which are common characteristics of benthic communities but are not relevant to the DQO of the proposed work. The Region is requested to provide the literature citations that it has relied on to make this determination.

- Sediment Chemistry Data - Region 2 identifies three DQOs for sediment chemistry data, including the need to develop correlations between benthic tissue concentrations and sediment, need to know the chemistry of feeding voids, and data for use in the bioaccumulation, and fate and transport models. Of the three DQOs identified by Region 2, the third DQO (collection of sediment data for use in the bioaccumulation, and fate and transport models) is the only one relevant in reducing uncertainty in applying the exposure zone CSM.

  The first DQO, developing correlations between tissue concentrations with specific sediment chemistry is not necessary, nor a practical requirement. Determining a biota sediment accumulation factor (BSAF) is more relevant, but the BSAF is based on a simple ratio between tissue concentrations and sediment concentrations, not on correlations. More importantly collecting sediment chemistry along with tissue samples is not possible given the methods needed to collect sufficient tissue sample for chemical analysis. With respect to the Region's second DQO, the CPG does not see the value in determining concentrations in sediment surrounding feeding voids. Feeding voids were rarely observed in Germano's 2005 LPRSA Sediment Profile Imaging Survey. Moreover, the CPG is unaware of a methodology to identify feeding voids in a sediment grab sample; the CPG invites the Region to elaborate on how this could be conducted.

  As presented in CPG's proposal, benthic tissue samples will be obtained by collecting composited tissue from numerous grab samples. In fact, the CPG sampling plan estimates that at least 160 grab samples will be needed to collect sufficient tissue sample to conduct 12 chemical analyses. Collecting sediment from each of the 160 grabs and expecting to develop meaningful correlations is not practical. Rather, given the large number of grab samples from which benthic organisms will be composited for the 12 tissue analytical samples, the CPG considers the resulting tissue chemical data to represent the site average. While collecting a focused number of sediment samples for use with the bioaccumulation, and fate and transport models, could reduce uncertainty in applying the exposure zone CSM, such samples would be better collected when determining the vertical position of benthic community members, not during tissue collection.

The CPG believes that site-specific exposure zone(s) could be resolved if the Region was willing to engage in a series of meaningful and substantive face-to-face meetings with experts from Region 2, EPA Headquarters and the CPG. How this matter is resolved is almost entirely up to the Region – the CPG would prefer an informal engagement with two teams of experts resolving the matter of an appropriate exposure zone(s).

The CPG requests that Region 2 include this letter into the Administrative Records for the 17-mile LPRSA operable unit of the Diamond Alkali Superfund Site and the Region's 8-mile FFS and Proposed Plan.

Please contact Bill Potter or me with any questions or comments.

Very truly yours,
de maximis, inc.

Robert H. Law, PhD
CPG Project Coordinator

cc: Ray Basso, EPA Region 2
Walter Mugdan, EPA Region 2
Sarah Flanagan, EPA Region 2
James Woolford, EPA HQ
Steve Ells, EPA HQ
CPG Members
William Hyatt, CPG Coordinating Counsel
Willard Potter, CPG Project Coordinator

DISPUTE STATEMENT ON EXPOSURE DEPTH (ZONE) ISSUES

LOWER PASSAIC RIVER STUDY AREA

17-MILE REMEDIAL INVESTIGATION/ FEASIBILITY STUDY

Prepared for
Lower Passaic River Cooperating Parties Group

Prepared by
Anchor QEA, LLC
(Woodcliff Lake, New Jersey; Boston, Massachusetts)

Windward Environmental, LLC
(Seattle, Washington)

de maximis, inc.
(Clinton, NJ)

With contributions from
Moffatt & Nichol (New York, New York)

November 2015

Introduction and Background

These documents have been prepared to support the formal Dispute Resolution process, as it relates to comments and assertions made by USEPA Region 2 (Region 2) on the findings of the Cooperating Parties Group (CPG) regarding the exposure depth or zone (hereafter exposure zone or EZ) issue for the 17-mile Lower Passaic River Study Area (LPRSA). The issue of what is an appropriate exposure zone has been discussed at two meetings between the Region and the CPG in February 2014 and February 2015. Following the February 2014 meeting, the CPG provided additional information on the matter at the request of Region 2 in a letter and attachments dated February 19, 2014. The Region did not provide a response to that letter and did not engage in further discussions with the CPG on this matter for a year - until February 2015. Nearly four months after the February 2015 meeting, Region 2 provided on June 1, 2015 its comments and assertions on the matter of a LPRSA exposure zone. Additional correspondence on this matter was received by the CPG by way of the Region's letters dated June 25, 2015 and July 9, 2015. As a result of the Region's June 1, 2015 letter, the CPG invoked dispute resolution pursuant to paragraph 64 of the May 2007 Administrative Order on Consent on June 12, 2015; this letter was acknowledged by the Region on June 25, 2015. The CPG sent a third letter on July 2, 2015 requesting the information that the Region had used to make its determinations; the Region responded to this request on July 9, 2015. The CPG provided draft Quality Assurance Project Plan (QAPP) worksheets for a proposed sampling program on September 17, 2015 to support the development of site-specific exposure zone(s).

Source of Disagreement/Dispute Between Region 2 and the CPG

There are two areas of disagreement between Region 2 and the CPG:

1. The depth at which the majority of benthic invertebrates feed and reside in the sediment bed of the LPRSA, and
2. Reliability and certainty of sediment chemistry concentration predictions for depth interval of less than 15 centimeters (cm), or approximately 6 inches.

Each of these issues will be separately discussed in this document, and for clarity and ease of review, the CPG's position on both areas of disagreement are presented in accompanying papers by Windward Environmental and Anchor QEA, respectively.

Site-Specific Exposure Zone At Which the Majority of Benthic Invertebrates Feed and Reside Is Supported by Site-Specific Data, USEPA Guidance and Previous Documents Prepared by the Region.

Much of the disagreement between the CPG and Region 2 regarding the depth at which benthic invertebrates reside and feed is a difference on the identification and use of an appropriate and site-specific exposure zone for those benthic invertebrates that serve as a food source for benthic-feeding fish, and how this depth relates to the structure of the biologically active zone (BAZ). First, it is important to clarify the CPG's position as follows:

- The EZ represents the zone in which the majority of benthic invertebrates that serve as a food source for fish reside, while the BAZ refers to the maximum depth to which the biological activity of benthic invertebrates occurs. The EZ can be viewed as a subdivision of the BAZ that is found near the sediment surface for these benthic invertebrates that serve as a food source. Because of the need for an oxygenated environment, most of the benthic invertebrates in the LPRSA are concentrated above the Redox Potential Discontinuity (RPD) that denotes the depth to which oxygen is present in the sediments. This is well-established and supported in the scientific literature such as Rosenberg (1978) where it was *"found that a high proportion of the animals were restricted to the upper 5 cm of the sediments in the Byfjord most probably as a result of the RPD-layer being close to the surface."*[1]
- In its June 1, 2015, letter, Region 2 states that it does not support a benthic community EZ *"as shallow as 2 cm"*. Interestingly, and contrary to their June 2015 and subsequent statements, Region 2 stated in a May 1993 draft scope of work[2] for the Diamond Alkali OU2 that "*the upper 2 centimeters of sediment correspond to the biological active zone and thus provide a good representation of exposure of biota to contamination*". The CPG is not aware of any significant change in the scientific literature of the last 20 years that would change the Region's 1993 position of an EZ of 2 cm for the LPRSA.
- In its July 9, 2015 letter, Region 2 states that it does not believe that the depth of the RPD correlates with the limit of the BAZ. The CPG agrees that the RPD does not represent the limits of the BAZ, but it does provide a vertical barrier to smaller benthic invertebrates burrowing deeper that are a primary food source to bottom feeding fish.
- It is important to note that the CPG has never claimed that all members of the benthic community are exposed to only the upper 2 cm of sediment. However, the important element of the EZ Conceptual Site Model (CSM) is that those members of the LPRSA benthic community that constitute the majority of the food resource for benthic-feeding fish reside near the surface, in aerobic sediment (i.e., upper 2 cm). The CPG does not claim that all biological activity in the LPRSA is restricted to the EZ, such that the BAZ equals the EZ. Rather, based on site-specific data, the CPG clearly has identified very limited instances where biological activity is found below the interval (i.e., greater than 2 cm) where most LPR benthic invertebrates reside and feed.

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[1] Quoted from Pearson and Rosenberg (1978).

[2] Scope of Work to Investigate and Assess Contamination in the Passaic River and Estuary which constitutes the Second Operable Unit of the Diamond Alkali Superfund Site. Page 3. Dated May 9, 1993

- The CPG agrees with statements made in EPA's 2009 guidance[3] , which states that *"it is important that the sediment samples collected be representative of the sediments where the species normally forages and not a homogenized sediment core representing the entire bed of contaminated sediment"*. It goes on to state that *"for most organisms, the surficial sediments are most reflective of the organism's immediate exposure/foraging history, and generally, smaller depths of the surficial layer, e.g., 0 to 2 cm, are preferred over larger depths, e.g., 0 to 30 cm"*. If further states that *"for deeper burrowing organisms such as some clams and polychaetes, slightly larger surficial depths, e.g., 0 to 5 cm, might be more appropriate of their recent exposure history"*. Thus, for the purposes of estimating future exposure concentrations for benthic invertebrates and bottom-feeding fish, it would seem more logical to rely on the sediment concentrations predicted for discrete depth intervals (e.g. 0-2 cm or 0-5 cm) rather than a homogenized average from 0-15 cm as Region 2 supports which is greater than and not representative of the actual exposure zone for most benthic invertebrates.

The use of a site-specific exposure zone of 2 cm is clearly supported by the LPRSA data and the scientific literature as well EPA's guidance and past documents prepared by Region 2. Section 1 of this document establishes lines of evidence that form the specific bases for a 2 cm exposure zone and are summarized as follows:

- The depth of the RPD is approximately 2 cm for the Lower Passaic River. The RPD provides a primary vertical barrier to deeper burrowing by small benthic invertebrates that serve as the primary food source to bottom feeding fish.
- Benthic invertebrates in the Lower Passaic River are dominated by species that live near the sediment surface.
- Benthic invertebrates in the LPRSA are dominated by detritivores that feed on material at the sediment surface.
- There is a lack of evidence of significant biological activity below the RPD (i.e., 2 cm) in the LPRSA.
- The biological community structure in the LPRSA is similar throughout the year.

<u>Region 2 Is Incorrect In Its Assertions Regarding the Reliability And Certainty of Sediment Chemistry Concentration Predictions For A Depth Interval of Less Than 15 cm</u>

In the June 1, 2015 letter, Region 2 stated that the average contaminant concentration over the top 15 cm of sediment should be used in the bioaccumulation model for the 17-mile LPRSA. This position is based, in part, on Region 2's contention that concentrations in an EZ as shallow as the top 2 cm cannot be reliably calculated by the CPG contaminant fate and transport (CFT) model. This contention derives from incorrect assertions made by Region 2 in its June 1, 2015 letter and in the subsequent letters dated June 25, 2015 and July 9, 2015. Region 2's conclusion

3 Estimation of Biota Sediment Accumulation Factor (BSAF) from Paired Observations of Chemical Concentrations in Biota and Sediment (EPA / 600 / R-06 / 047 ERASC-013F February 2009)

is completely unsupported and contrary to the results of their own 2014 FFS CFT model which computes concentrations for 0 to 2 cm layers that are different than deeper layers such as 10-15 cm. The CPG believes and is confident that its sediment transport (ST) model which is derived from the same model used by the Region in its 2014 Focused Feasibility Study (FFS) can reliably predict bed elevation changes at scales as small as 2 cm. Additionally, this is supported by the ability of the CPG's version of the models to accurately predict water column contaminant concentrations (i.e., matching the levels measured in the Chemical Water Column Monitoring [CWCM] program), and provides confidence in the CFT model's concentrations in the 0 to 2 cm layer.

Region 2 also contends that the CFT model's average concentration over the top 15 cm is a reasonable surrogate for the average concentration in the top 2 cm. It does so without evidence and in direct contradiction to its own 2014 FFS model. The CPG disagrees with this contention, and will demonstrate that this is not supported by site-specific data.

Section 2 of this document, prepared by Anchor QEA, LLC, demonstrates why Region 2's assertions are incorrect and the Region's direction to use the 15 cm average to represent the 2 cm average is indefensible and contrary to their own modeling results.

The CPG's position and conclusions on the use of a 2 cm exposure zone are technically correct and are supported by the CPG's 17-mile LPRSA model and to a lesser extent the Region's 2014 FFS model:

- The modeling framework employed in both CPG and Region's versions of the models operate with processes occurring on a scale of a cm or less, because they actually occur in the river on that scale. Thus, the sediment transport (ST) and chemical fate and transport (CFT) models can reliably calculate concentrations in sediment at the scale of 0 to 2 cm because fate and transport processes occur on this scale.
- The 17-mile CWCM empirical data constrain and validate the models predictions of 0 to 2 cm sediment concentrations.
- Contrary to the Region's assertion, the CFT model's 0 to 15 cm average concentrations are poor surrogates for the 0 to 2 cm concentrations. A comparison of paired top 2 cm and top 15 cm sediment concentrations for chemicals of potential concern support the 2 cm predictions.

Summary

The Region has failed to provide any substantive and cogent basis for denying the use of an exposure zone as shallow as 2 cm. The Region's arguments have continued, throughout the nearly 2 years of this issue to be either (1) vague and generalized and rely largely on invoking an undefinable uncertainty, (2) providing partial or incorrect information to support its position, or (3) more recently saying data collection would take too long or be too complicated. This has been true since the dispute began with the Region's June 1, 2015 letter and continues with its recent letter on October 23, 2015. Additional hurdles have been presented with Region 2's positions:

- The Region's May 2014 expert paper prepared by a contractor to CDM-Smith was incomplete and severely flawed because it cited maximum burrowing depths and ignored data that the vast majority of benthic invertebrates reside within a few centimeters of the surface.
- The Region is either ignoring or contradicting the results of its own 2014 FFS model when it states that the model cannot reliably predict concentrations for intervals of less than 15 cm.
- The Region has inexplicably changed it position on a 2 cm exposure zone as evidenced by its May 1993 OU 2 Scope of Work.
- The Region has been reluctant if not unwilling to meet with the CPG and have meaningful exchange on this matter – it has avoided meeting on this issue with the CPG since February 2015.

In response to the Region's invitation in its June 1, 2015 letter, the CPG has prepared a draft QAPP and provided key worksheets to the Region to support the collection of data to develop a site-specific exposure zone. In short, Region 2's responses have prevented the CPG from finalizing and utilizing a site-specific and truly representative exposure zone for the 17-mile RI/FS. The CPG believes that the confrontational approach of dispute resolution on site-specific exposure zone(s) could be avoided and the matter resolved if the Region is willing to engage in a series of meaningful and substantive face-to-face meetings with experts from Region 2, EPA Headquarters and the CPG.

DISPUTE STATEMENT ON EXPOSURE DEPTH ISSUES PERTAINING TO EXPOSURE DEPTH (ZONE) CONCEPTUAL SITE MODEL

17-MILE LOWER PASSAIC RIVER STUDY AREA REMEDIAL INVESTIGATION/ FEASIBILITY STUDY

Prepared for

Cooperating Parties Group

November 6, 2015

Prepared by: Windward environmental LLC

200 West Mercer Street, Suite 401 □ Seattle, Washington □ 98119

Table of Contents

Figures

Acronyms

BAZ	biologically active zone
CPG	Cooperating Parties Group
CSM	conceptual site model
EZ	exposure zone
FWM	food web model
LOE	line of evidence
LPR	Lower Passaic River
LPRSA	Lower Passaic River Study Area
PCA	principal components analysis
Region 2	US Environmental Protection Agency Region 2
RM	river mile
RPD	redox potential discontinuity
SDI	Swartz's Dominance Index
SPI	sediment profile imaging

1 Source of Disagreement/Dispute Between USEPA Region 2 and CPG

There are two areas of disagreement between the US Environmental Protection Agency Region 2 (Region 2) and the Cooperating Parties Group (CPG):

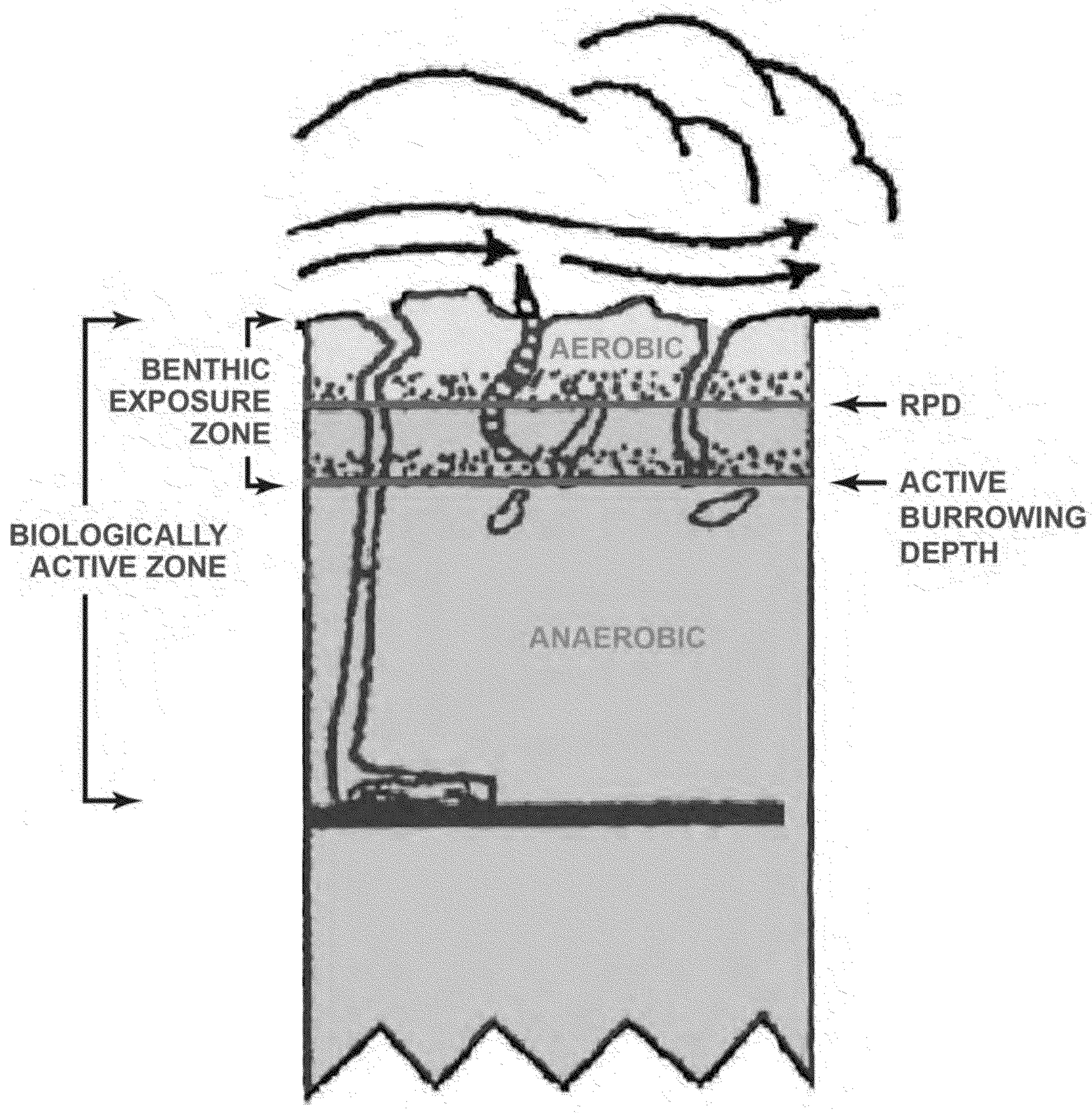
1. The depth at which the majority of benthic invertebrates feed and reside in the sediment bed of the Lower Passaic River (LPR)
2. Reliability and certainty of sediment chemistry concentration predictions for the depth interval of less than 15 cm (6 in.); this area of disagreement is discussed by Anchor QEA in Volume 2 of this document

Much of the disagreement between CPG and Region 2 regarding the depth at which benthic invertebrates reside and feed is the result of a) a difference in the identification and use of an appropriate and site-specific exposure zone (EZ) for those benthic invertebrates that serve as a food source for benthic-feeding fish, and b) how this depth relates to the structure of the biologically active zone (BAZ).

1. The EZ represents the zone in which the majority of benthic invertebrates that serve as a food source for fish reside, while the BAZ refers to the maximum depth to which the biological activity of benthic invertebrates occurs. For the benthic invertebrates that serve as a food source, the EZ can be viewed as a subdivision of the BAZ that is found near the sediment surface (Figure 1). Because of the need for an oxygenated environment, most of the LPR benthic invertebrates are concentrated above the redox potential discontinuity (RPD) boundary, which is typical in such an environment. This fact is well established and supported in the scientific literature, such as Rosenberg (1977), wherein it was "found that a high proportion of the animals were restricted to the upper 5 cm of the sediments in the Byfjord most probably as a result of the RPD-layer being close to the surface" (Pearson and Rosenberg 1978).
2. In its June 1, 2015, letter to CPG, Region 2 stated that it does not support a benthic community EZ as shallow as 2 cm (Vaughn 2015a). Interestingly, and contrary to its June 2015 statements, Region 2's May 1993 draft scope of work for Diamond Alkali Operable Unit 2 stated that "the upper 2 cm of sediment correspond to the biological active zone and thus provide a good representation of exposure of biota to contamination" (USEPA 1993).
3. In its July 9, 2015, letter to CPG, Region 2 states that it does not believe that the depth of the RPD layer correlates to the limit of the BAZ (Vaughn 2015b). CPG agrees that the RPD layer does not represent the limits of the BAZ, but it does provide a vertical barrier that prevents smaller benthic invertebrates, a primary food source for bottom-feeding fish, from burrowing deeper than the RPD layer.

4. Moreover, CPG has never claimed that **all** members of the benthic community are exposed to only the upper 2 cm of sediment. However, the important element of the EZ conceptual site model (CSM) is that those members of the Lower Passaic River Study Area (LPRSA) benthic community that constitute the **majority** of the food resources for benthic-feeding fish reside near the surface, in aerobic sediment (i.e., upper 2 cm). CPG does not claim that **all** biological activity in the LPRSA is restricted to the EZ, such that the BAZ equals the EZ. Rather, based on site-specific data, CPG clearly has identified limited instances where biological activity is found below the interval (i.e., deeper than 2 cm) where most LPRSA benthic invertebrates reside and feed.

The following sections present the analyses and lines of evidence (LOEs) that form the basis for CPG's conclusions concerning the portion of the benthic community that serves as the primary source of food for benthic-feeding fish.



Source: Figure revised from Swift et al. (1996); color and labels have been added.

Figure 1. CSM of the LPR EZ

2 Background

The fundamental question addressed herein is "At what depth in the sediment of the LPR do the majority of benthic invertebrates, which serve as a food source for benthic-feeding fish, reside?" Fish species that rely on benthic invertebrates (i.e., invertivores) and / or living and dead organic matter (i.e., benthic omnivores) as a food source typically feed at the sediment surface, or by sifting through material in the upper few centimeters of the sediment surface.

When sediments are contaminated, knowing the depth at which the majority of the benthic invertebrates live is important, since this food source serves as a trophic mechanism to transfer contaminants associated with sediment to higher trophic organisms. Based on an evaluation of multiple LOEs that rely on LPRSA site-specific data and a review of published literature for other water bodies, the CPG has concluded that the EZ for benthic invertebrates that serve as the primary food source for benthic-feeding fish is in the upper several centimeters of the sediment surface. Becker and Chew (1987), for example, investigated flatfish foraging behavior over the diurnal cycle in an urban environment. The fish they studied were opportunistic feeders that predominantly fed on what was most abundant in the upper few centimeters of sediment, the common polychaetes *Capitella* spp. Rhoads et al. (1978) concluded that since productivity in early successional stages generally exceeds that of later stages, benthic assemblages dominated by pioneering species represent an enhanced food resource for demersal fishes. Based on fish community and tissue collection surveys in the LPRSA (Windward 2011, 2010), it is clear that the majority of fish in the LPRSA are benthic feeders and opportunistic omnivores. Therefore, it is highly probable that LPR benthic-feeding fish feed selectively on shallow-dwelling and abundant infaunal invertebrates.

2.1 EXPOSURE ZONE CONCEPTUAL MODEL

The CSM of the LPR EZ is presented in Figure 1. The vertical profile of sediment in the LPR consists of multiple physiochemical and biotic zones. Because oxygen is a fundamental factor in organism survival, the principal physiochemical zone is based on the presence of oxygen. Oxygenated sediments are found at the sediment surface, while deeper sediments lack oxygen. The depth at which sediment is found to be oxygenated depends on a number of factors, including the availability of oxygen in the overlying water, the relative biological oxygen demand of the sediment, and the degree to which the sediment is actively reworked by benthic invertebrates. The demarcation between the oxygenated aerobic zone and the anaerobic zone, where oxygen is lacking, is termed the RPD layer. When viewed in profile, sediments that contain oxygen are often light tan in color due to the presence of particles coated with ferric hydroxide, while reducing sediments that lacks oxygen appear darker (Germano & Associates 2005).

Since benthic invertebrates only can survive in conditions where oxygen is present, the majority of benthic invertebrates live within the aerobic zone, where oxygen is prevalent. In Figure 1, this means that they live in the near-surface sediment above the RPD. Some benthic invertebrates have adapted to be able to exploit anoxic sediment, and thus can be found below the RPD. However, any organisms located below the RPD always maintain contact with the oxygenated surface sediment or overlying water. Examples of such organisms include deep-burrowing clams, which can be found at depth, but the siphons of which are found at the sediment-water interface for feeding and respiration; certain species of polychaetes and oligochaetes, which form vertical tubes to the surface that are irrigated with overlying water; and polychaetes, which build burrow galleries that are also irrigated with overlying, oxygenated water.

The following sections present the LOEs that form the basis for CPG's conclusions concerning the location of the benthic community that serves as the primary source of food for benthic-feeding fish. LOEs that support CPG's conclusions, include:

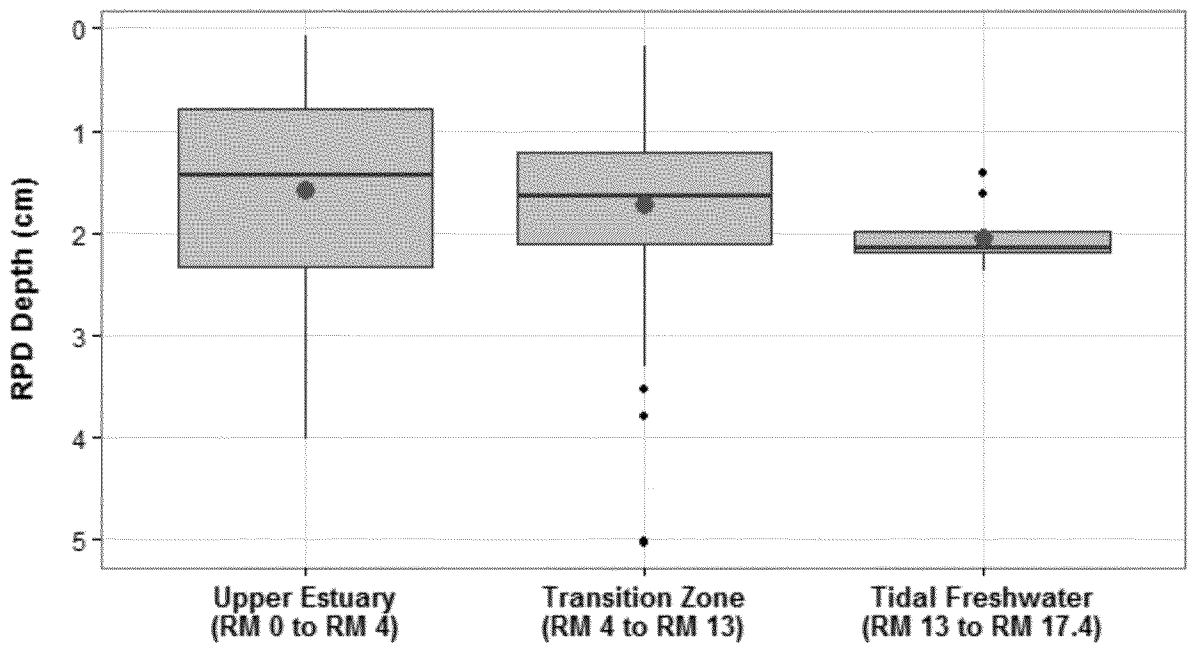
- The depth of the RPD boundary is approximately 2 cm for the LPR.
- Benthic invertebrate abundance in the LPRSA is dominated by species that live near the sediment surface.
- Benthic invertebrate biomass in the LPRSA is dominated by detritivores that feed on material at the sediment surface.
- There is a lack of evidence of significant biological activity below the RPD in the LPRSA.
- The biological community structure in the LPRSA is similar throughout the year.

3 Analysis and Conclusions

3.1 The Depth of the RPD is Approximately 2 cm for the LPRSA

The RPD was measured using sediment profile imaging (SPI) surveys conducted by Germano & Associates (2005) over a five-day period in June 2005. This method evaluates the contrast in optical reflectance between the aerobic and anaerobic layers of sediment. Shallow, overlying aerobic sediments appear olive or tan in color because of the ferric hydroxide, whereas deeper, underlying anoxic sediments appear grey or black in color. The distinguishable boundary between the two layers is defined as the RPD.

Germano & Associates (2005) took 2 image replicates at 5 stations along each of the 27 cross-river transects, yielding a total of 268 images from 134 stations (only 4 stations at Transect 27 could be surveyed). Using Germano & Associates (2005) data, the mean RPD depths for the LPRSA were 1.6 cm for the upper estuary (LPRSA river mile [RM] 0 to RM 4), 1.7 cm for the transition zone (RM 4 to RM 13), and 2.1 cm for the tidal freshwater zone (RM 13 to RM 17.4) (Figure 2). For the purposes of developing the benthic-to-fish trophic transfer component of the LPRSA food web model (FWM), the CPG rounded the RPD to 2 cm.



Source: data reported by Germano & Associates (2005)
Note: Blue points indicate the mean RPD depths within each of the three zones.

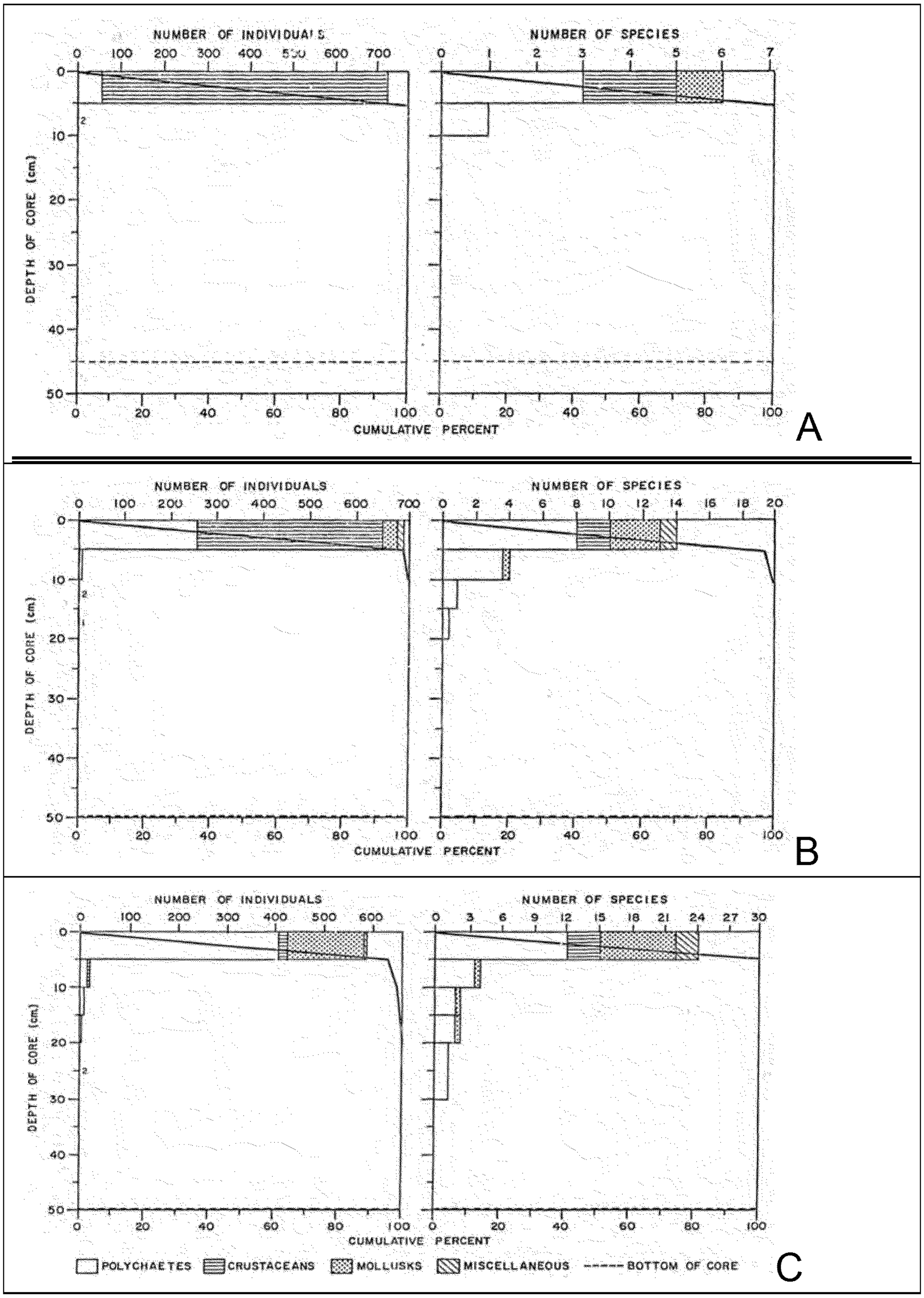
Figure 2. Distributions of RPD depths across the three zones within the LPR

3.2 BENTHIC INVERTEBRATE ABUNDANCE IN THE LPRSA IS DOMINATED BY SPECIES THAT LIVE NEAR THE SEDIMENT SURFACE

Based on the results of the SPI survey data, Germano & Associates (2005) concluded that benthic invertebrate communities in the LPRSA are generally in a state of early or transitional community succession. Even in locations where species associated with mature communities (i.e., head-down deposit feeders) are found, the community is most often dominated by a small number of species (e.g., the oligochaete *Limnodrilus hoffmeisteri*) (Windward 2014a) that often live near the sediment surface. Some stations farther upstream (i.e., in the tidal freshwater zone) are inhabited by more stable, mature, and diverse communities of invertebrates (Germano & Associates 2005; Windward 2014a). Data from the fall 2009 and spring and summer 2010 community surveys (Windward 2014a, b) noted the presence of many species that in the literature, are associated with early successional stages (e.g., small-bodied, relatively mobile opportunists that feed near the sediment surface on detrital material) (Pearson and Rosenberg 1978; Rhoads and Germano 1986; McCall and Soster 1990; Soster and McCall 1990; Germano & Associates 2005).

Communities in early and transitional stages of succession are characteristically inhabited by species of invertebrates that live near the sediment surface and feed on very shallow surface sediment and detrital matter (i.e., detritivore feeding guild), rather than feed and / or live deeper in sediment, consuming bedded sediment (i.e., deposit feeder guild) (Pearson and Rosenberg 1978; Rhoads and Germano 1986; McCall and Soster 1990; Soster and McCall 1990). Early and transitional stages were observed visually in June 2005 using SPI (Germano & Associates 2005) and are fairly abundant members of the LPRSA benthic community, particularly in the upper estuary zone (RM 0 to RM 4) (Windward 2014a, b).

As a whole, benthic communities in upper estuary and transition zone waters are exposed primarily in shallow sediment, where the majority of benthic biomass is most often found (Mermillod-Blondin et al. 2001; Kirchner 1975; Nilsen et al. 1982). Figure 3 provides a visualization of the typical distribution of biomass over depth. It is expected that the biomass in shallow sediment (rather than the relatively sparse, deeply buried biomass) accounts for the vast majority of what is transferred up the food chain to fish (PWS RCAC 2004). For example, fish and crabs generally do not consume whole, buried bivalves, but rather “nip” or “crop” the siphon tubes of those bivalves that are available near the sediment surface (Kvitek and Beitler 1991; Kanakaraju et al. 2008). Deep burrowing is often a strategy to avoid predation (Flynn and Smee 2010); as a result, such burrowing is expected to reduce the level of trophic transfer of contamination from bedded sediment to higher trophic levels via benthic invertebrate tissues. Additionally, deep burrowing organisms, such as bivalves, feed at the surface and from the overlying water column. Consequently, the concentrations to which these organisms are exposed are likely to be more consistent with concentrations in surface sediment than with those in sediment below the RPD.



Source: Figure format revised from Nilsen et al. (1982).

Note: Panels A and B show results from two sampling locations in muddy bottoms; panel C shows result from a mixed sand and mud location.

Figure 3. Vertical distribution of abundance and taxa in soft sediments

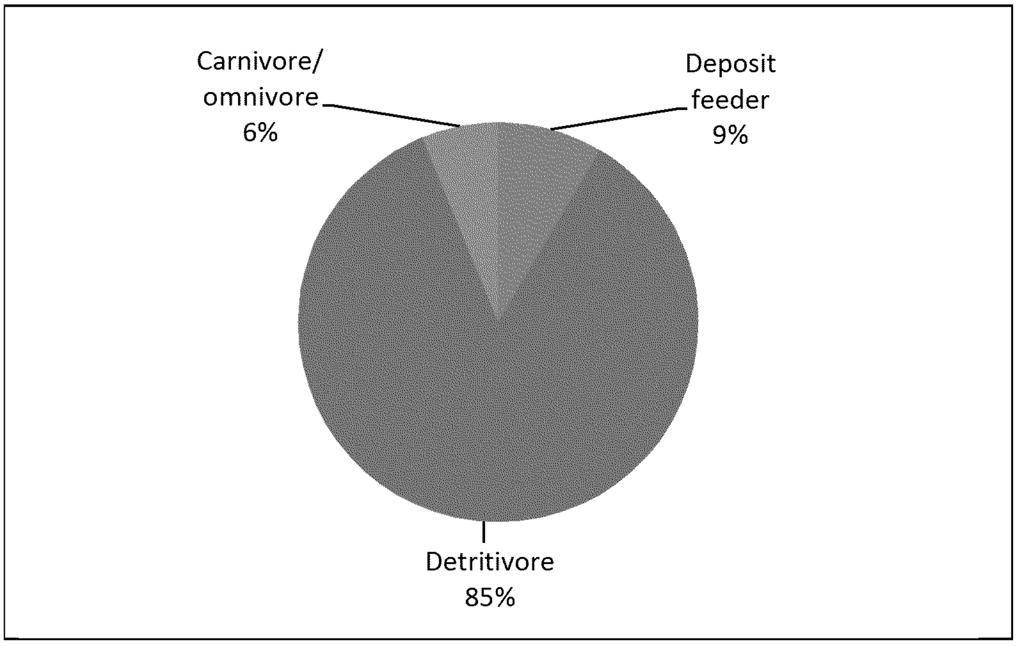
3.3 BENTHIC INVERTEBRATE BIOMASS IN THE LPRSA IS DOMINATED BY DETRITIVORES THAT FEED ON MATERIAL AT THE SEDIMENT SURFACE

CPG conducted a detailed investigation of the feeding strategies of each observed taxonomic group from the fall 2009 and spring and summer 2010 surveys (Windward 2014a, b). The strategies were reported or inferred from available literature and databases (e.g., Fauchald and Jumars 1979; Vieira et al. 2006; Macdonald et al. 2010; USEPA 2012). The majority of species in the LPRSA were found to most likely consume some type of detrital material, including leaf litter, fluff (or flocculated, unconsolidated surface sediment), or suspended particulates (e.g., algae, disturbed fluff, sewage, or other solid runoff).

As noted, there is a fairly shallow RPD layer in the LPRSA (2 cm or less on average), and the community structure and successional stages in the LPRSA indicate that most species are opportunistic feeders and feed and live in shallow sediment (rather than feeding on deep, bedded sediments) (Germano & Associates 2005; Pearson and Rosenberg 1978). These LOEs support the claim that benthic invertebrates in the LPRSA are dominated by species that feed on surface material.

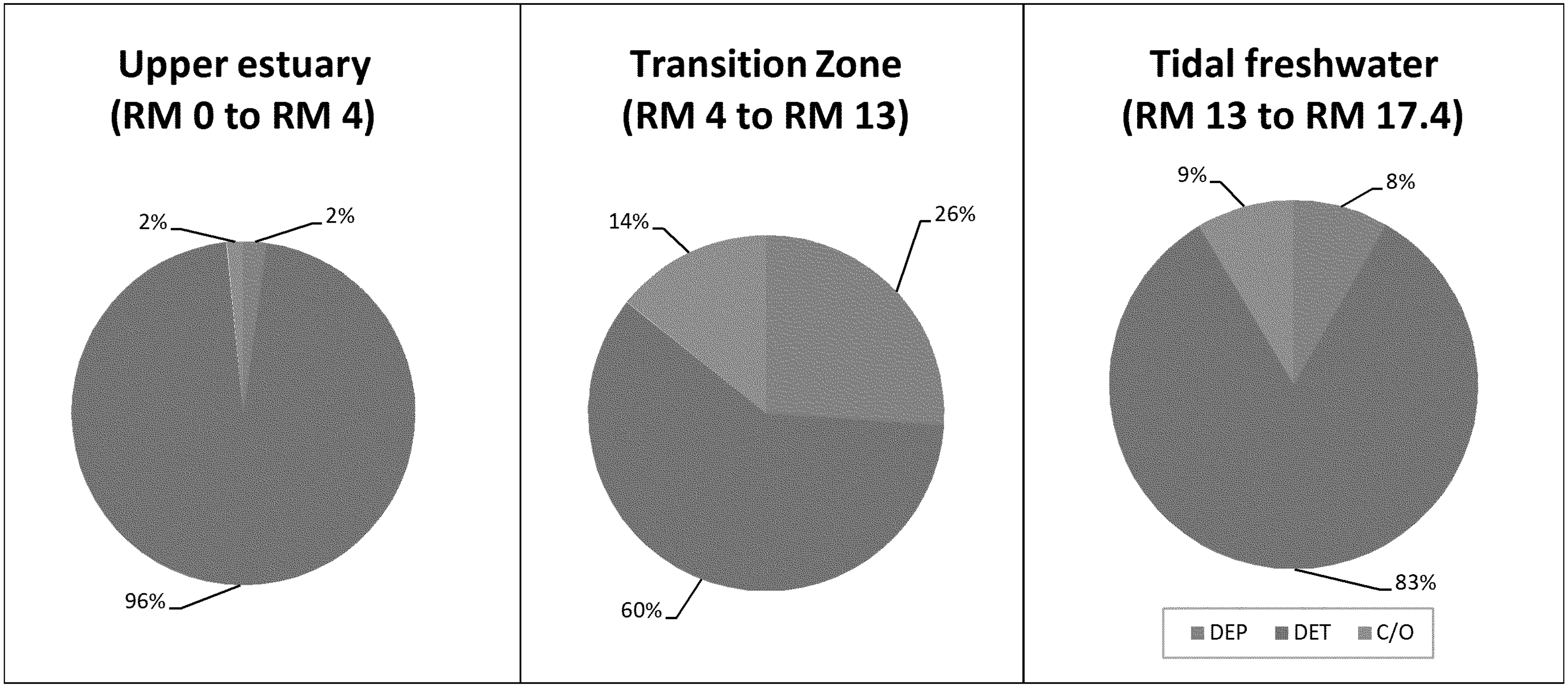
In order to better understand the structure of the benthic community and to meet the information needs of the FWM, the CPG estimated the biomass of all species found in each of the three salinity zones. Biomass of invertebrates was estimated using biomass values from the literature (i.e., mass-per-individual) (CBBMP 2014; Whiles and Goldowitz 2005; Barbone et al. 2007; Bloom et al. 1972; Douce 1976; Ricciardi and Bourget 1998; Smit et al. 1993; Sapkarev 1967; Newton 2013) and site-specific abundance data (fall 2009) (Windward 2014a). Based on the best available estimate, detritivores account for approximately 85% of all biomass across the LPRSA (Figure 4) and dominate biomass within each salinity zone. Detritivores account for a greater portion of the biomass in the upper estuary zone (96% of total biomass) and tidal freshwater zone (83%) than in the transition zone (60%) (Figure 5). Primary surface feeding species include small-sized bivalves (e.g., *Macoma balthica* and *Corbicula* sp.), which are suspension (filter) feeders and / or near-surface deposit feeders. Other examples of such species include small crustaceans (e.g., *Gammarus* spp.), many species of worms (e.g., *Marenzelleria viridis*), and larval insects (e.g., many species within family Chironomidae). Maximum burrowing depths presented by Prezant (2014) in his analysis as an expert for Region 2 are not the same as typical burrowing depths, which are generally much shallower (e.g., 4–6 cm for *M. balthica*) (Aller and Yingst 1985), especially for the small-sized individuals collected in the LPRSA. Representative samples of LPRSA benthic invertebrate individuals collected during the benthic community surveys of 2009 and 2010 and shown to Region 2 staff during the January 27, 2015, meeting were small relative to published size ranges. Within the same species, smaller individuals can be expected to burrow to shallower depths than larger individuals.

Based on the foregoing, CPG concluded that the vast majority of the sediment-dwelling organisms present in the LPRSA that serves as forage for upper-trophic level consumption is represented by shallow-burrowing, surface-feeding detritivores; as such, this majority supports the use of a shallow (i.e., 2-cm) EZ in the CPG FWM.



Note: Carnivore/omnivore category includes predators, predator/parasites, and omnivores, all of which will consume live tissue as available. Deposit feeders directly consume sediment. Detritivores consume a variety of materials, including coarse plant matter, fluff, and particulates.

Figure 4. Site-wide distribution of estimated LPRSA biomass (fall 2009) among generalized feeding types



DEP – deposit feeder DET – detritivore C/O – carnivore/omnivore

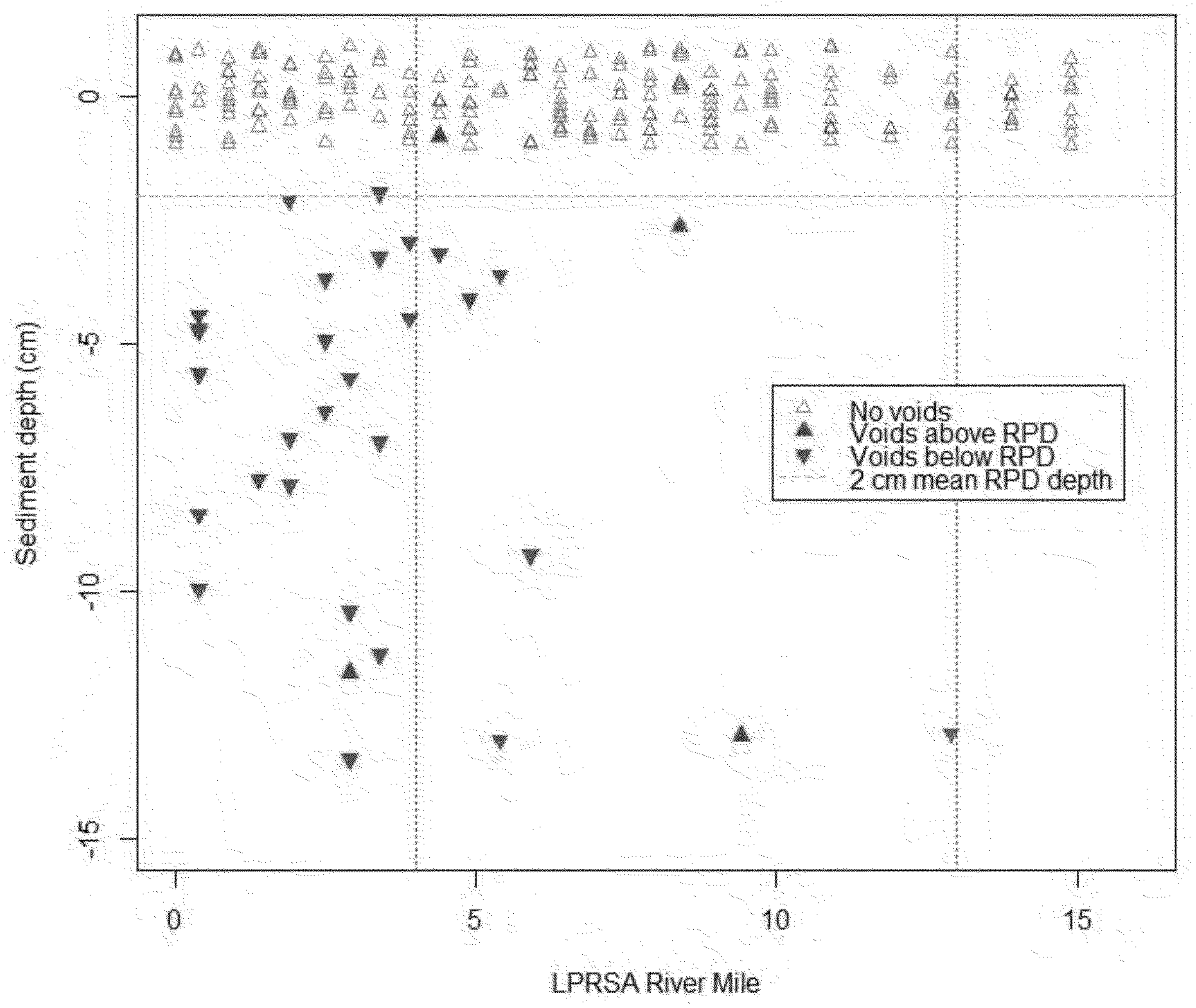
Note: Carnivore/omnivore category includes predators, predator/parasites, and omnivores, all of which will consume live tissue as available. Deposit feeders directly consume sediment. Detritivores consume a variety of materials, including coarse plant matter, fluff, and particulates.

Figure 5. Within-zone distributions of estimated LPRSA biomass (fall 2009) among generalized feeding types

The use of a shallow EZ for the FWM is not a novel approach. The models of contaminant transfer from sediments to benthic invertebrates for the Housatonic and Hudson Rivers both assumed mixing depths between 4 and 10 cm (Connolly 2015), shallower than the typical BAZs observed for these rivers, which generally ranged between 15 and 20 cm. These shallower mixing zones were assumed to be the source of most contamination entering the aquatic food web from the benthic zone.

3.4 THERE IS A LACK OF EVIDENCE OF SIGNIFICANT BIOLOGICAL ACTIVITY BELOW THE RPD IN THE LPRSA

The 2005 SPI survey (Germano & Associates 2005) provided an analysis of 269 images taken along transects along the lower 15 mi of the LPR. Bottom conditions above RM 15 contained too much sand or cobble to allow images to be obtained. For each of the 269 images, Germano & Associates (2005) noted the presence of feeding voids and the depths at which they were found. Consistent with the EZ CSM, the SPI photographs identified some biological activity below the RPD. Also consistent with the EZ CSM, the presence of biological activity, as evidenced by the presence of feeding voids, was rarely identified, only appearing in approximately 10% of the images (28 of 269). Region 2, in its response to the CPG's analysis of the LPRSA benthic community EZ, included a graphic plot showing the presence of feeding voids below the RPD that was based on the interpretation of the SPI images by Germano & Associates (2005). This graph is misleading, as it shows only the stations where a feeding void below the RPD was observed (which was only found in 10% of the images) and ignores the rest of the observations on feeding voids presented in the dataset. Figure 6 plots the depth of observed feeding voids for all 269 images. From Figure 6, it is obvious that biological activity, in the form of feeding voids below the RPD, is a relatively rare occurrence in the LPRSA. When all of the data are presented (stations where feeding voids were not detected are shown as jittered around 0 cm in Figure 6), the observations show a pattern of biological activity that is consistent with the EZ CSM. The CPG has not stated that the BAZ does not extend beyond the RPD, but rather that the evidence of such activity is rare in the empirical data available for the LPRSA. The abundant benthic invertebrates collected in the 2009 and 2010 surveys (Windward 2014a, b), the literature-based categorization of many of the species living and feeding near the sediment surface, and the small size of the benthic invertebrates all support the conclusion that the majority of the LPRSA benthic community resides within the EZ and above the RPD.



Source: Data reported by Germano & Associates (2005).

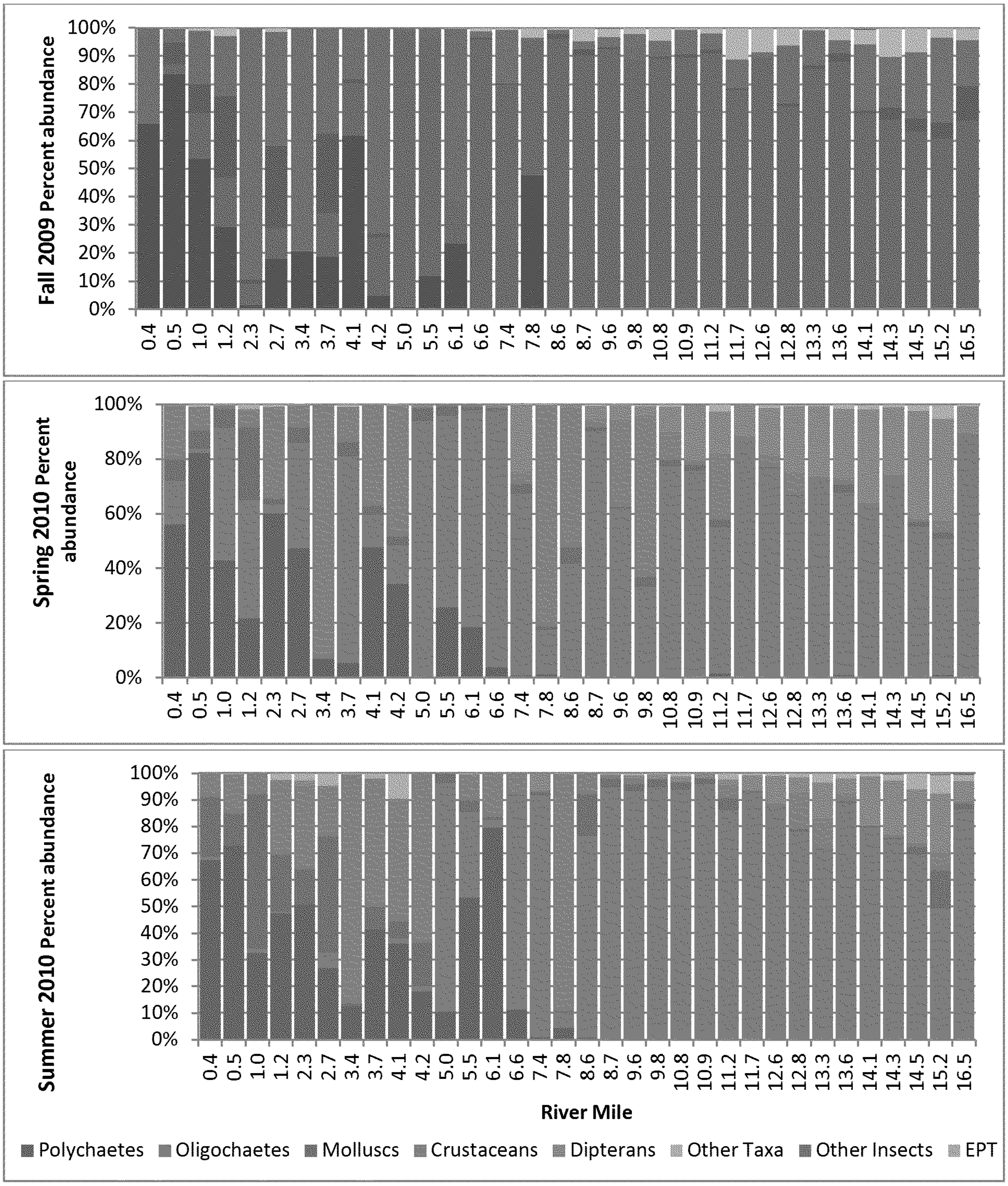
Note: Sampling locations where no voids were observed are jittered around 0 cm to show the number of locations at which there was no evidence of feeding in proportion to locations where voids were observed. The categorization of locations as above or below the RPD is based on the location-by-location RPD values. Vertical, dashed lines indicate breaks between salinity zones. The four locations with voids above the RPD layer tended to have fine, recently deposited sediment. Profile images from those locations showed a fully oxidized sediment profile or a faint or indistinguishable RPD boundary (Germano & Associates 2005).

Figure 6. Maximum depth of active or relict feeding voids in SPI photographs

3.5 THE BIOLOGICAL COMMUNITY STRUCTURE IN THE LPRSA IS SIMILAR THROUGHOUT THE YEAR

Sediment for benthic invertebrate community analysis (i.e., taxonomy and structure) was collected at 33 sampling locations in the LPRSA over three seasons (i.e., fall 2009 and spring and summer 2010) (Windward 2014a, b). All stations were reoccupied in order to provide a measure of consistency among seasons. Based on these surveys, it appears that differences in benthic invertebrate community structure in the LPRSA remain fairly consistent throughout the year. Figure 7 presents the major taxonomic groups at individual sampling locations (sorted from downstream to upstream) over three seasons, and the community structure looks fairly similar across all seasons.

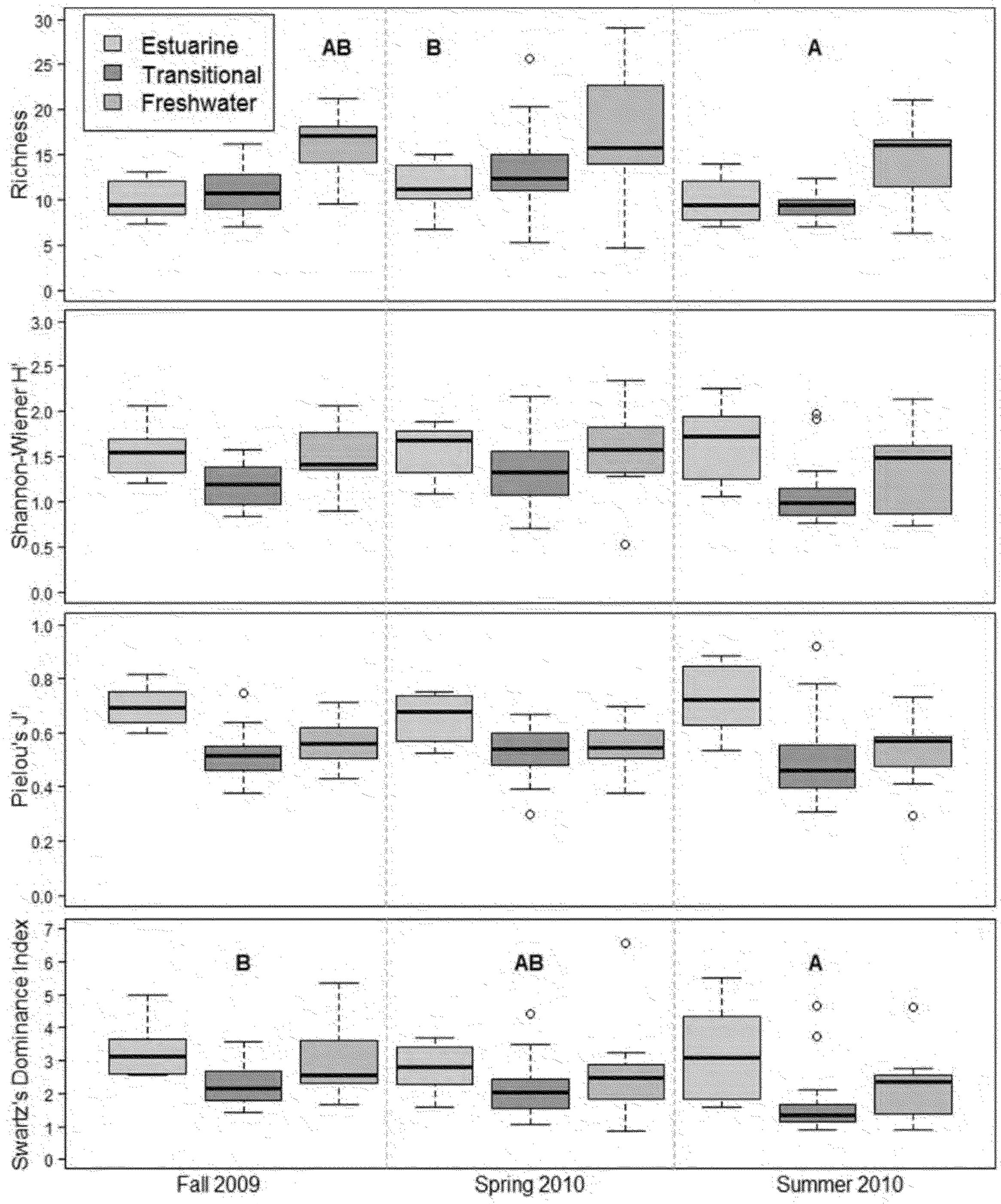
Slight changes in community structure are noticeable within salinity zones. For example, mollusks are more prevalent in the upper estuary zone during the summer, whereas oligochaetes are more prevalent in the spring. Similarly, polychaetes appear to shift further upstream in the summer and fall than in the spring. These changes are consistent with the known seasonal migration of the salt wedge in the LPRSA resulting from higher freshwater flows during the spring and lower flows in summer and fall. The tidal freshwater zone appears to change very little in composition across seasons.



EPT – Ephemeroptera, Plecoptera, Trichoptera

Note: Only re-sampled locations are shown. Chironomidae are included in Dipterans category; Other Insects category includes all non-Dipteran and non-EPT insects; Other Taxa category includes all other non-insect taxa, including Turbellaria, Nematoda, Nemertea, Hirudinea (leeches), and others.

Figure 7. Comparison of major benthic invertebrate taxonomic groups present in the LPRSA for the 2009 and 2010 surveys



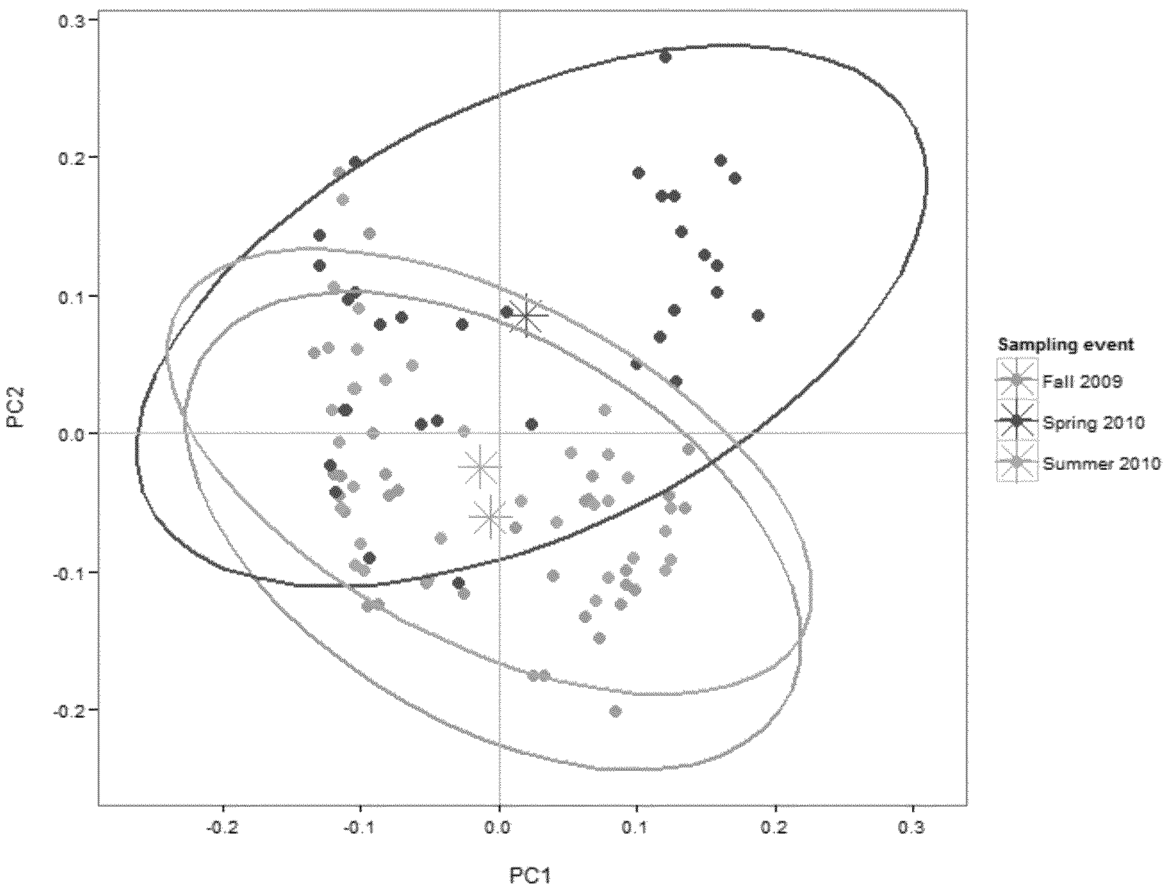
Note: Letters have been added where applicable to indicate results of non-parametric Kruskal-Wallace test (alpha = 0.05) with Steel-Dwass-Critchlow-Fligner multiple comparison (alpha = 0.05); uppercase/bold letters, where applicable, indicate results of comparison among seasonal events; after Bonferroni correction for multiple comparison, only richness was significantly different among seasons (experiment-wise alpha = 0.05); estuarine, transitional, and freshwater zones are synonymous with the upper estuary, transition zone, and tidal freshwater zones, respectively

Figure 8. Benthic invertebrate community metrics in the LPRSA from 2009 and 2010 sampling events

The richness of invertebrates was significantly less in the summer than in the spring (Figure 8). Similarly, Swartz's Dominance Index (SDI) was significantly less in summer 2010 than in fall 2009. After correction for multiple comparisons (i.e., Bonferroni correction, experiment-wise alpha = 0.05), seasonal differences were no longer significant. This suggests that the difference in SDI among seasons is uncertain. Additional metrics of community structure (Figure 8) indicate that differences among seasons were not significant.

Deeper analysis of the 2009 and 2010 taxonomic data results in a similar conclusion, that seasonality plays a minor role in structuring the benthic invertebrate community, particularly when compared to the role of habitat conditions. For example, Figure 9 shows the results of a principal components analysis (PCA) using benthic invertebrate abundance data for the 20 most abundant taxa across all 33 sampling locations and 3 sampling events. The proximity of points in Figure 9 indicates how similar (or dissimilar, for distant points) each sampling location was to the others in terms of the abundance of dominant taxa.

Prior to analysis, the data were log-transformed and then scaled within species to give each of the species equal weighting. The PCA output for each sampling location was then labeled according to either the sampling event or the salinity zone for that location. Ellipses were then drawn around each grouping of data to show a 95% confidence limit around the average value for PC1 and PC2 (centroid) (multivariate t-distributed, alpha = 0.05). Groups are significantly different if the centroid of one group is outside of the ellipse of another. As noted, Figure 9 shows that dominant benthic invertebrate species are generally similar across seasons, with the species found between the fall 2009 and summer 2010 sampling events being particularly similar.



PC – principal component

Note: Invertebrate communities sampled during each event are significantly different if the centroid (asterisk) of one group is outside of the ellipse of another. PC1 and PC2 collectively explain 60% of the variance in community structure based on the 20 most abundant taxa across all three sampling events.

Figure 9. PCA biplots of seasonal LPRSA benthic invertebrate abundance data

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DISPUTE STATEMENT ON EXPOSURE DEPTH ISSUES PERTAINING TO FATE AND TRANSPORT MODELING

LOWER PASSAIC RIVER STUDY AREA REMEDIAL INVESTIGATION/ FEASIBILITY STUDY

Section 2

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LIST OF ACRONYMS AND ABBREVIATIONS

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
cfs	cubic feet per second
CFT	contaminant fate and transport
cm	centimeter
CPG	Cooperating Parties Group
CWCM	Chemical Water Column Monitoring
FFS	Focused Feasibility Study
FS	feasibility study
ft^2	square feet
LPR	Lower Passaic River
LPRSA	Lower Passaic River Study Area
m	meters
ng/kg	nanograms per kilogram
PWCM	Physical Water Column Monitoring
RI	remedial investigation
ST	sediment transport
sv-CWCM	small volume Chemical Water Column Monitoring
tetra-CB	tetrachlorobiphenyl

1 INTRODUCTION

In a June 1, 2015 letter to the Cooperating Parties Group (CPG), Region 2 of the U.S. Environmental Protection Agency (Region 2) took the position that the average contaminant concentration over the top 15 centimeters (cm) of sediment is most appropriate to represent contaminant concentrations in the benthic community exposure zone for use in the bioaccumulation model for the Lower Passaic River Study Area (LPRSA) 17-mile Remedial Investigation (RI) and Feasibility Study (FS). This topic was discussed at two meetings between the Region and the CPG in February 2014 and 2015 and the CPG had presented the case for a layer shallower than 15 cm. One of the arguments for this position is the contention that concentrations in a shallower layer, and specifically the top 2 cm of sediment, cannot be reliably calculated by the CPG's contaminant fate and transport (CFT) model, which is based on the Region's CFT model. As a result, the CPG invoked dispute resolution pursuant to paragraph 64 of the May 2007 Administrative Order on Consent on June 12, 2015, which was acknowledged by the Region on June 25, 2015. The CPG sent a letter on July 2, 2015 requesting the "additional material" that Region 2 relied upon in evaluating the CPG's work on a proposed exposure depth for the 17-mile LPRSA; the Region responded on July 9, 2015 with this information.

The Region's contention derives from three incorrect assertions made by Region 2 in the June 1 letter and in a subsequent letter dated July 9, 2015:

- Region 2 claims the CFT model computes relationships between concentrations in the 0 to 2 cm layer and the 0 to 15 cm layer that are inconsistent with measurements.
- Region 2 also claims that the CPG's sediment transport (ST) model cannot reliably predict bed elevation changes at scales as small as 2 cm.
- Region 2 claims that accurately predicting water column contaminant concentrations (i.e., matching the levels measured in the Chemical Water Column Monitoring [CWCM] program) provides no confidence in the CFT model's concentrations in the 0 to 2 cm layer.

Region 2 also contends that the CFT model's average concentration over the top 15 cm is a reasonable surrogate for the average concentration in the top 2 cm. It does so without evidence and in direct contradiction to its own model.

In this document, the CPG demonstrates why Region 2's assertions are incorrect and why it is indefensible to use the 15 cm average to represent the 2 cm average as Region 2 directs.

Section 2 explains that sediment transport and contaminant transfer are controlled by processes occurring at scales much finer than 15 cm, which is why ST and CFT models are built to represent these scales. Section 3 demonstrates the logical relationship between 0 to 2 and 0 to 15 cm concentrations in site-specific data and model predictions, which implies that the CPG model calculates realistic 0 to 2 cm concentrations. Section 4 explains that the ST model's predictions rest on its ability to realistically represent centimeter-scale bed elevation processes and its behavior at this scale is constrained by multiple datasets. Section 5 explains why the CWCM data constrain the calibration of the 0 to 2 cm concentrations. Section 6 explains that Region 2's direction to use the 15 cm average in favor of the 2 cm average is inconsistent with the model setup and predictions, and relying on it significantly biases broad-scale averages. The best estimate of the 2 cm average concentrations comes from the model predictions of this interval.

2 THE CPG'S AND REGION 2'S MODELS CALCULATE CONCENTRATIONS IN SEDIMENT AT THE SCALE OF 0 TO 2 CM BECAUSE FATE AND TRANSPORT PROCESSES OCCUR ON THIS SCALE

The Region 2 and CPG CFT models represent the top 15 cm of sediment as a stack of 1 cm thick layers. Models are constructed with such fine vertical resolution as a general practice because of the generally accepted notion that vertical gradients need to be represented. Examples beyond Region 2's Focused Feasibility Study (FFS) model and the CPG model of the Lower Passaic River (LPR), are the models developed for the Hudson River, the Grasse River, and the Fox River Superfund sites.

Hudson River: A vertical discretization of two centimeters was used for the HUDTOX sediment segmentation to provide adequate resolution of vertical PCB profiles for simulating sediment-water interactions and long-term system responses. (USEPA 2000, page 58)

Grasse River: The bed model was constructed using twelve 1-inch layers to simulate PCB transport in the sediments. (Alcoa 2010, page A4-14)

Fox River: The upper two layers are each 2 centimeters thick and represent biologically active sediments. The third layer is 6 centimeters thick and represents biologically inactive sediments. (HQI 2001, page 21)

Models are constructed this way because water column contaminant concentrations and long-term trends in sediment contaminant concentrations are largely controlled by contaminant concentrations in the top few centimeters of sediment. Diffusion between the bed and the water column is governed by the gradient in concentration between the water column and sediments within the top 1 cm or so. Resuspension is largely derived from the top few centimeters or less, except in extreme events. This is so because resistance to erosion increases rapidly with depth, such that erosion stops a short distance into the bed. The Region 2 analysis of SedFlume erosion measurements in the LPR concluded the critical shear stress for erosion was four times higher at 2 cm than at the surface, increasing to ten times higher at 5 cm and further still as depth increased (see Table 1; Table 3-7 of LBG et al. 2014, Appendix B II).

It seems inexplicable for Region 2 to argue that model predictions for the top few centimeters are unreliable when its model is constructed to explicitly calculate concentrations in this depth interval because they are key to being able to properly represent contaminant fate and transport. Moreover, the processes operating on these scales are constrained by calibration to the available data within both the ST model (Section 4) and the CFT model (Section 5).

3 THE PAIRED TOP 2 CM AND TOP 15 CM SEDIMENT CONCENTRATION DATA FOR CHEMICALS OF POTENTIAL CONCERN SUPPORT THE 2 CM PREDICTIONS

3.1 Region 2 Contention in the June 1 and July 9 Letters

A review of the limited dataset of finely segmented cores with contaminant concentrations from depths of less than 15 cm shows significant variability: sometimes the surface concentrations are higher than concentrations averaged over the top 15 cm and sometimes they are lower. (Region 2 June 1, 2015 letter)

… the concentration of 2,3,7,8-TCDD averaged over 15 cm compared to the concentration at the top 2 cm is highly variable. While this is not a statistically valid dataset from which to draw conclusions about 2 cm concentrations across the river, the results do suggest that there are insufficient data from the top 2 cm to evaluate model performance. (Region 2 July 9, 2015 letter)

Despite the fact that the limited data set shows high variability, based on the modeling files provided to EPA in December 2014, the CPGs modeled predictions over 2 cm are consistently lower than those predicted over 15 cm on a reach averaged basis and over the vast majority of individual grid cells in the LPRSA. Over the duration of the 1995-2013 calibration period, the CPG's model predictions of 2,3,7,8-TCDD in the top 2 cm average less than half of the concentration in the top 15 cm. Given the variability in the limited 2 cm data set, EPA does not have confidence in these modeling results; they would need to be verified through the collection of additional data. (Region 2 July 9, 2015 letter)

3.2 Cooperating Parties Group Response

The CPG disagrees with Region 2's contention that the CPG CFT model exhibits behavior inconsistent with the available 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) data relating 2 cm average and 15 cm average concentrations. Additionally, the models are sufficiently calibrated for the various processes that govern this behavior such that the validity of the model results can be judged in the absence of additional measurements of 2 cm average concentrations.

While Region 2 is correct in stating "the concentration of 2,3,7,8-TCDD averaged over 15 cm compared to the concentration at the top 2 cm is highly variable," it failed to recognize that the variability is explainable, consistent with the conceptual model of the site and with the CPG CFT model predictions. Rather than being evidence against reliance on model predicted 2 cm averages, these data support such reliance.

A structure emerges when the relationships between 2 cm average and 15 cm average concentrations are examined more closely than was done by Region 2.[1] The ratio of these concentrations in individual samples decreases with increasing 15 cm average concentration (Figure 1). The highest ratio (3.6) is at the lowest 15 cm concentration (10 nanograms per kilogram [ng/kg]), the second highest ratio (1.6) is at the next lowest 15 cm concentration (98 ng/kg), and the lowest ratio (0.2) is at the highest 15 cm concentration (4,134 ng/kg). The ratio averages 0.9 for the six samples with 15 cm concentrations in the range of 200 to 500 ng/kg.

Displaying the model results in the same format as Figure 1, Figures 2a and 2b show that the model generates the same trend as the data and is numerically consistent with the data for both 2,3,7,8-TCDD and tetrachlorobiphenyl (tetra-CB), respectively, which is evident comparing the red dots (data) to the black dots (model). Thus, the model is calculating realistic relationships between 2 cm and 15 cm concentrations, which supports its use to set exposure concentrations for the bioaccumulation model.

The model's vertical profiles have an intuitive structure that is evident in the average profiles for individual depositional regimes (Figures 3a and 3b). Areas that are strongly depositional over the long-term calibration period (greater than 1 cm/year) exhibit a nearly constant concentration from the surface to 15 cm. This condition results in a ratio of the 2 cm average to the 15 cm average approaching 1 (i.e., no vertical gradient), because sediments throughout the upper 15 cm reflect fairly recent deposition. In contrast, areas that are erosional or non-depositional exhibit a gradient with higher concentrations at depth and ratios of

[1] In addition to the eight finely segmented cores Region 2 selected, one core (G0000181 collected under 2007-2008 Sediment Sampling Program), with a surface slice of 2.5 cm located near the mouth of the LPR, was included in this analysis.

approximately 0.4 for both 2,3,7,8-TCDD (Figure 3a) and tetra-CB (Figure 3b), because high legacy concentrations have not been buried below 15 cm.

The behavior of the model and the data are consistent with the measurements of 2,3,7,8-TCDD concentrations on water column particulate matter and recently deposited material. These concentrations reflect concentrations in the top few centimeters of sediment because that is the primary contemporary source of 2,3,7,8-TCDD to the water column. They are typically a few hundred ng/kg (Table 3-8 of LBG et al. 2014, Appendix B II; Figure 4-3 of LBG et al. 2014, Appendix C; Figure 6-5a of Anchor QEA et al. 2015). Therefore, the 2 to 15 cm concentration ratio should generally be close to one when 15 cm concentrations are a few hundred ng/kg. It should generally be higher at lower concentrations and lower at higher concentrations. This behavior is shown by both data (Figure 1) and model (Figures 2 and 3).

Region 2's distrust of a vertical gradient in the upper 15 cm mean concentration is puzzling given that its FFS model produces even stronger vertical gradients than the CPG model (Figures 4a and 4b), and these gradients played a central role in Region 2's initialization and calibration of the FFS model. In particular, Region 2 imposed a vertical gradient on the model initial conditions for the upper 15 cm because "after running the model initially … the sediments developed a gradient over the top 15 cm (~6 in). This gradient is controlled mainly by the rate of particle mixing within the bed" (LBG et al. 2014). Vertical gradients in areas of high 0 to 15 cm concentration are unavoidable unless one homogenizes the 0 to 15 cm interval (e.g., by imposing intense sediment mixing), which would lead to excess contaminant depletion at the sediment-water interface and an unrealistic rapid decline in the 0 to 15 cm average concentration (based on the CPG's experience).

The CPG also disagrees with Region 2's contention that the 0 to 2 cm concentration "would need to be verified through the collection of additional data" before they can confidently be used. The vertical profile predicted by the model is a logical consequence of the contaminant mass balance and the well-accepted contaminant fate and transport processes underlying the model structure, which are constrained by joint calibration to the 15 cm sediment bed data and the water column data. The vertical structure that forms in the sediment bed over the top 15 cm is the result of net chemical sources and sinks acting at the surface (water column interaction) and at the bottom of this interval (interaction with deeper sediments below 15 cm), as well as internal redistribution (mixing). The net sources and sinks acting at the surface are constrained by the CWCM data because net mass entering and leaving the bed at the surface determines the water column concentrations. The overall average 15 cm concentrations are constrained by the sediment bed data. Having a model with deterministic physical processes calibrated to both the average of the structure (15 cm average) and the net sinks or sources at the surface produces a constrained vertical structure. Although Region 2 has challenged the value of the CWCM data to the CPG calibration, the principle of simultaneously calibrating the bed and the water column is not controversial and has been implicitly agreed on by Region 2 and the CPG since the start of the modeling effort; this is demonstrated by the Modeling Work Plan (HQI 2006) and the data use objectives of the small volume CWCM (sv-CWCM) program (AECOM 2011). The need to adequately specify the vertical profile of contaminants and the concentrations near the sediment water interface is implicit in requiring that a model reproduce water column fluxes. The CPG does not disagree that more data on near surface sediments would be useful; however, the absence of additional data does not disqualify the use of 0 to 2 cm concentrations from the model that have been calibrated in the manner envisioned throughout the RI/FS process.

Further support for using the model results for the 2 cm average comes from comparing those results to measured 2 cm average concentrations. A larger dataset[2] exists for 2 cm concentrations than for the dataset of matched 2 and 15 cm concentrations. Figure 5 compares 2 cm 2,3,7,8-TCDD and tetra-CB concentrations within the LPR measured in the late-2000s to values computed by the model for the matching grid cells. Exact comparability is not expected for several reasons; for instance, a spatial average over the area of a model cell is being compared to a point measurement within that area. The degree of comparability that exists is similar to the level of calibration for the 15 cm concentrations in Region 2's FFS model.

[2] In additional to the Region 2 selected eight 0 to 2 cm samples from the 2008 CPG Low-resolution Coring Program, samples with a 0 to 2.5 cm interval from the 2007-2008 Sediment Sampling Program and the 2007 U.S. Environmental Protection Agency Empirical Mass Balance Model Program were included in the analysis.

4 THE VALIDITY OF SEDIMENT TRANSPORT COMPUTED ON THE SCALE OF CENTIMETERS IS SUPPORTED BY THE PERFORMANCE OF THE SEDIMENT TRANSPORT MODEL

4.1 Region 2 Contention in the June 1 and July 9 Letters

The sediment transport model has been calibrated using the bathymetry change dataset, the accuracy of which is a direct function of the uncertainties of the individual bathymetry datasets … (Region 2 June 1 and July 9, 2015 letters)

The existing bathymetry change dataset cannot resolve changes as finely as 2 cm, due to factors including instrument accuracy and changes in surface sediment density (i.e., reflectiveness). (Region 2 July 9, 2015 letter)

… which means that the model cannot reliably predict bed elevation changes at scales as small as 2 cm. This means that there is no way to determine if the solids calculated to be present in the top 2 cm are, in fact, present in a particular grid cell or present but buried by subsequent deposition. Since the contaminant fate and transport model's predictions of contaminant concentrations are driven by bed characteristics passed to it by the sediment transport model, this inability to reliably predict bed elevation changes at 2 cm scales would further add to the uncertainty in the predicted contaminant concentrations in the 2 cm layer. The contaminant fate and transport model cannot be expected to produce reliable estimates of contaminants present in the top 2 cm if the sediment transport model cannot produce reliable estimates of the solids transport at this high level of vertical resolution. (Region 2 July 9, 2015 letter)

4.2 Cooperating Parties Group Response

Sediment transport in the LPR and most other sites is modeled using centimeter-scale resolution and models depend on the reliability at this scale to accurately represent the system being modeled.

Erosion processes typically occur on the scale of a few centimeters. Region 2 recognizes this and constructed its sediment transport model with critical shear stresses for the initiation of erosion and erosion rates at various shear stresses that decline greatly moving centimeters into the bed. This can be seen in Table 3-7 of the Region 2 FFS sediment transport model report (LBG et al. 2014, Appendix B II), which is reproduced here as Table 1. Representing these gradients is necessary because erosion and deposition occurring in most events are restricted to the top few centimeters.

To demonstrate this fact, the average erosion depths calculated by the CPG sediment transport model for a range of high flow events are presented in Figure 6. For events with peak flow less than 10,000 cubic feet per second (cfs) (i.e., corresponding to a return period of just under 5 years), the cells experiencing erosion have on average less than 1 cm of erosion. Only the single largest event (Hurricane Irene) over the calibration period has an average greater than a few centimeters.

It is puzzling that Region 2 would claim that the ST model is unreliable on the scale of several centimeters, given that both the Region 2 and CPG CFT models rely on the ability of the ST model to predict centimeter-scale processes that govern water column contaminant levels and long-term trends in sediment contaminant levels.

Region 2 ignores the fact that the bathymetric change dataset is only one of several types of data used to calibrate the ST model. It has been calibrated to the solids fluxes and suspended solids concentrations at various locations in the LPR and over various events and to surficial bed sediment composition from various datasets. Calibrating to multiple metrics and events ensures that surface sediment dynamics, which occur on the centimeter-scale, are reasonably represented and that bathymetric changes resulting from these dynamics, which also occur on the centimeter-scale for much of the river, are reasonably predicted at the spatial resolution of the model.[3] Among these calibration checks are the long-term burial rates, which overall are on the order of centimeters per year. Both the Region 2 and CPG models are able to reasonably replicate the rates obtained from measurements.

[3] The sub-grid scale variability does not invalidate the predictions at the scale represented by the model and is a factor affecting all models of natural phenomena. Moreover, sub-grid scale processes affect all aspects of the modeling and the 2 cm layer is not unique in this regard.

The model's capability in capturing the dynamics at the sediment surface can be seen in its response as it transitions from conditions when one process (erosion) predominates, to conditions when both erosion and deposition occur in the LPR. This response during and following large storm events is shown on the right side of Figure 6. During such events, given the above-average currents and shear stresses in the LPR, the model erodes through the more erodible surficial sediment layers until it exposes a sediment layer with shear strength greater than the imposed shear stress. Following the storm event, under more quiescent conditions when shear stresses are lower, any erosion in such areas can only occur from sediments deposited following the storm event (which presumably have less shear strength than the underlying sediments exposed during the storm). Therefore, the model's ability to reproduce the surficial sediment dynamics of erosion and deposition is essential to reproducing the suspended sediment dynamics following the storm event. These processes and the performance of the model can be seen in its comparisons to: 1) the data from a 16,000 cfs event in March 2010 (an event with a return period of 25 years; documented in Section 5.4.2. of Appendix M of the RI Report; Anchor QEA et al. 2015); and 2) the data from the Spring 2010 Physical Water Column Monitoring (PWCM) survey in the LPR, which commenced shortly after the high-flow event of March 2010 (documented in Section 5.4.3 of Appendix M of the RI Report; Anchor QEA et al. 2015). The comparisons show that the model performs reasonably in reproducing the measurements during the predominantly erosional conditions associated with the storm event, as well as the measurements reflecting erosional and depositional processes during the relatively lower flow conditions following the storm event. If the model was limited in its ability to reproduce the surficial sediment dynamics, then it would also be limited in its ability to reproduce the measurements during the spring 2010 survey. Therefore, these comparisons provide a measure of confidence in the model's ability to reproduce the surficial sediment dynamics.

Moreover, Region 2 is wrong in stating that bathymetric change estimates are too imprecise to be used to calibrate sediment transport at the 2 cm scale. Both its FFS ST model and the CPG ST model have used them for this purpose, and appropriately so. Region 2's assertion comes from considering only the accuracy of individual bathymetry measurement points, not the accuracy of averages of those measurements over the area of a model grid element. An average of the individual measurements has greater accuracy than the measurements themselves. As explained below, the average elevations within each model grid cell are known with sufficient accuracy sub-centimeter precision and provide a way to check model predictions of elevation change on the scale of the 2 cm layer at issue.

The greater accuracy of average bed elevation comes from the well-known fact that the variance of that average is the variance of the individual independent measurements divided by the number of measurements.

Suppose individual measurements have a variance of 10 cm^2 (which means a standard deviation of 3.2 cm and a 95th percentile uncertainty of 13 cm; reasonable uncertainty for multi-beam measurements), the variance of the average of 100 measurements is 0.1 cm (i.e., 10/100) and the 95th percentile uncertainty is 1.3 cm, ten times less than the individual measurements. This impact of averaging is illustrated in Figure 7.

Multibeam data exist at a resolution of 1 square foot (ft^2), which means that 100 measurements are obtained in a 10-foot by 10-foot area. The high accuracy at this scale relative to each measurement is the reason that evaluations of cutline elevations and backfill elevations on the Hudson River dredging project are done at this scale. Those evaluations require accuracy of a few centimeters to assess attainment of the required dredge depth while minimizing unnecessary over-dredging.

The grid elements in the CPG sediment transport model have a typical size of 60 meters (m) by 180 m (RI Report Appendix K; Anchor QEA et al. 2015), which equates to an area of 116,000 ft^2. If each measurement had a 13 cm uncertainty band, the uncertainty band of the average of the 116,000 elevation measurements would be 0.05 cm.

Achievement of this accuracy is evident comparing model grid element bed elevation averages calculated from 2007 and 2008 bathymetric surveys. Because no significant high flow events occurred between these surveys, large changes in bed elevation are not expected (except in some highly depositional areas and in the vicinity of structures that induce secondary flows). The grid cell averages should mostly be very similar. That is the case as can be seen in Figure 67 from Appendix M of the RI Report (Anchor QEA et al. 2015). The data shown in that figure are presented here as a frequency plot (Figure 8). Approximately

35% of the grid cells had essentially identical elevations (less than 2 cm different) and approximately 70% had differences less than 5 cm.

5 THE CWCM DATA CONSTRAIN AND VALIDATE MODEL PREDICTIONS OF 0 TO 2 CM SEDIMENT CONCENTRATIONS

5.1 Region 2 Contention in the July 9 Letter

EPA disagrees with the CPG's assertion that the water column contaminant data provide a constraint on the 2 cm bed concentrations, because the water column concentrations are controlled by contaminant concentrations in the fluff layer and the CPG's model includes a parameter to control the transfer of contaminants between the upper layer of the bed and the fluff layer. The combination of the transfer parameter and contaminant concentrations in the upper layer of the bed (below the fluff layer) control contaminant flux to the water column. This provides a non-unique link between the water column and the bed below the fluff layer. While alternate combinations of bed concentrations and transfer parameters could reproduce water column contaminants equally well, the bioaccumulation model would be affected by these alternate choices. (Region 2 July 9, 2015 letter)

5.2 CPG Response

As noted in Section 3, the Region 2-authored LPR/Newark Bay Modeling Work Plan (HQI 2006) envisioned the need for water column data to calibrate the model's flux of contaminants between the bed and the water column (HQI 2006). This need is expressed in the objectives in the Region 2-approved sv-CWCM Program Quality Assurance Project Plan (AECOM 2011; "… the data provide information to develop the inputs to the model and to characterize the transport of contaminants in the LPRSA and NBSA, including the preliminary calibration of the flux of contaminants from the sediments to the water column through routine monitoring events").

The contaminant flux to the water column is controlled by the near-surface bed contaminant concentration and the solids flux. The Region 2 and CPG models are conceptually consistent in this regard; however, the CPG model offers a more refined representation that includes a fluff layer. The model tracks the contaminant within this millimeter-scale layer so as to prevent unrealistic contaminant mixing between depositing particles and underlying sediments over the short time scale of a tidal cycle. Although the interaction between the water column and the parent bed is influenced by the fluff layer, the water column flux is still controlled by the concentrations in the surface of the parent bed and the transfer of contaminants between that layer and the fluff layer, and the parent bed interacts directly with the water column if the fluff layer is not present, as during erosion events.

The "parameter to control the transfer of contaminants between the upper layer of the bed and the fluff layer" (Region 2 July 9, 2015 letter) was calibrated to the CWCM data and resulted in a calibration value equivalent to the sediment mixing intensity for both 2,3,7,8-TCDD and tetra-CB. This value is calibrated to the sediment 15 cm average and is well within literature values (Table 1 of Appendix K in CPG RI Report; Anchor QEA et al. 2015; Boudreau 1994; Thoms et al. 1995; Olsen et al. 1981).

The logical coupling between 2 cm concentrations and water column concentrations can be demonstrated by increasing the parent bed and fluff layer exchange. Increasing the rate of contaminant exchange between the parent layer and the fluff layer such that parent layer and fluff concentration approach one another (essentially no fluff layer), causes the mean 2 cm concentrations to decline compared to the calibration (shown for 2,3,7,8-TCDD in Figure 9; blue versus orange line). The contaminant mass that is lost from the bed appears as an over-predicted water column response and the quality of the water column calibration declines (the "model-to-data residual" [see Appendix K, Section 4.1.1, of Anchor QEA et al. 2015] increases 320% compared to the calibrated value for 2,3,7,8-TCDD; a larger value is a lower quality calibration). Various combinations of parameter values could provide a quality calibration; however, it is the CPG's experience examining alternative combinations that the 2 cm mean concentrations remain similar when constrained by both the 15 cm sediment data and the CWCM data.

6 THE CFT MODEL'S 0 TO 15 CM AVERAGE CONCENTRATIONS ARE POOR SURROGATES FOR THE 0 TO 2 CM CONCENTRATIONS

6.1 Region 2 Contention in the June 1 Letter

A review of the limited dataset of finely segmented cores with contaminant concentrations from depths of less than 15 cm shows significant variability: sometimes the surface concentrations are higher than concentrations averaged over the top 15 cm and sometimes they are lower. If these data suggest anything, it is that a 15 cm composite reasonably represents concentrations at shallower depths. (Region 2 June 1, 2015 letter)

It is EPA's position that the existing RI data from the top 6 inches (approximately 15 cm) of sediment, and model concentration simulation results for this depth interval, should be used to represent contaminant concentrations for this parameter [exposure depth]. (Region 2 June 1, 2015 letter)

6.2 Cooperating Parties Group Response

Region 2 is invoking model uncertainty as a reason in and of itself to support the use of 0 to 15 cm as the exposure depth, implying that this directive should stand even though "varying depths of benthic community exposure zone less than 15 cm may be appropriate for parts of the LPRSA" (Region 2 July 9, 2015 letter).

Region 2 is thereby arguing that the model's prediction of the 15 cm average is a better predictor of the 2 cm average concentration than the model's actual prediction of the 2 cm average. The CPG finds this argument to be unreasonable for several reasons:

- The CPG model's 0 to 2 cm concentrations are constrained and reasonable, as detailed in the preceding sections. The model was designed to resolve processes on this scale, and the model's 0 to 2 cm concentration is the best predictor available.
- Both the Region 2 and CPG models predict vertical gradients that make the 15 cm average different in most cases from the 2 cm average. In areas that are non-depositional or erosional, the 15 cm average is considerably higher and thus averages that include such areas will be biased high if the 15 cm concentration is used as a surrogate for the 2 cm concentration. This fundamental result is expected due to the

well-established processes upon which the model is based, and is unavoidable via calibration.

- Using the 15 cm average implies a paradoxical set of assumptions whereby the assumed exposure depth (15 cm) exceeds the model's present mixing depth (10 cm), which is physically not possible because biota would be exposed to contaminants that they cannot access (as noted by the CPG in its comments to Region 2 on the FFS model). At a minimum, the model would have to be recalibrated to allow mixing down to 15 cm. Calibration may be possible if the mixing were slow enough to prevent unrealistic depletion of the 15 cm average; however, this case would still result in a strong vertical gradient in the average concentration during baseline conditions such that the 15 cm average would remain a poor and biased surrogate for the 2 cm average.

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TABLES

Table 1
Parent Bed Erosion Rates for Cohesive Areas

Top (cm)	0	2	5	10	15	20	45	70
Bottom (cm)	2	5	10	15	20	45	70	320
Thickness (cm)	2	3	5	5	5	25	25	250
Tau (dyn/cm^2)	**Erosion Rate (cm/s)**							
2	8.27E-05	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09
4	5.79E-04	8.38E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09
8	2.63E-03	7.67E-05	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09
16	1.03E-02	5.50E-04	3.37E-05	3.91E-06	2.28E-06	2.10E-06	2.07E-06	2.07E-06
32	3.82E-02	2.52E-03	3.31E-04	1.35E-04	1.18E-04	1.16E-04	1.16E-04	1.16E-04
64	1.37E-01	9.94E-03	1.65E-03	8.20E-04	7.43E-04	7.33E-04	7.32E-04	7.32E-04
128	4.83E-01	3.67E-02	6.70E-03	3.57E-03	3.27E-03	3.24E-03	3.23E-03	3.23E-03
tau crit	1.0	4.0	9.7	13.4	14.0	14.1	14.1	2000.0

Notes:
cm = centimeter
cm/s = centimeters per second
dyn/cm^2 = dyne per square centimeter
Source: Table 3-7 of LBG et al. (2014), Appendix B II.

FIGURES

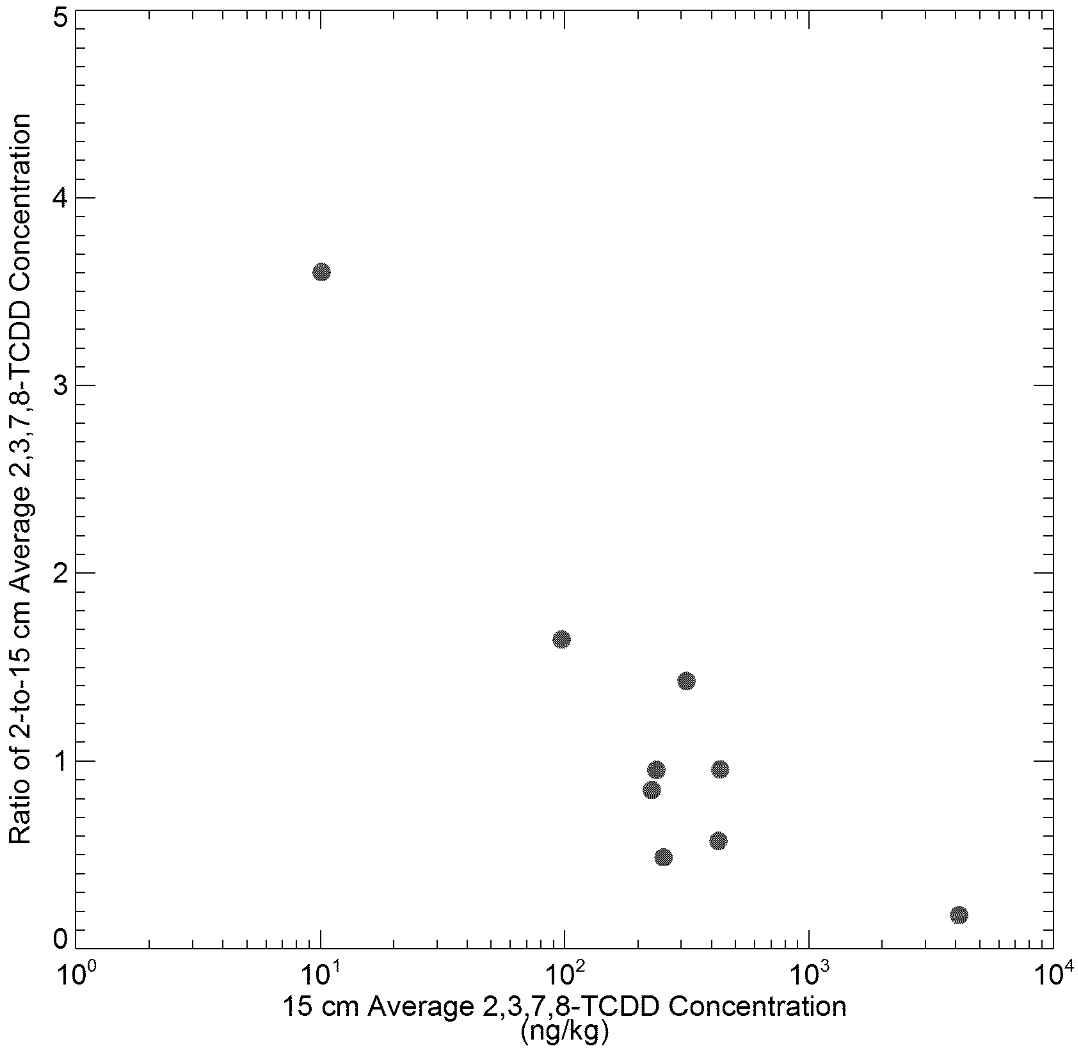

Figure 1

Measured 2 cm and 15 cm Average Concentration Ratio
Versus 15 cm Average Concentration for 2,3,7,8-TCDD
Exposure Depth Dispute Resolution

Eight Region 2 selected CPG finely segmented cores and one core from 2007-2008 sediment sampling program are shown.

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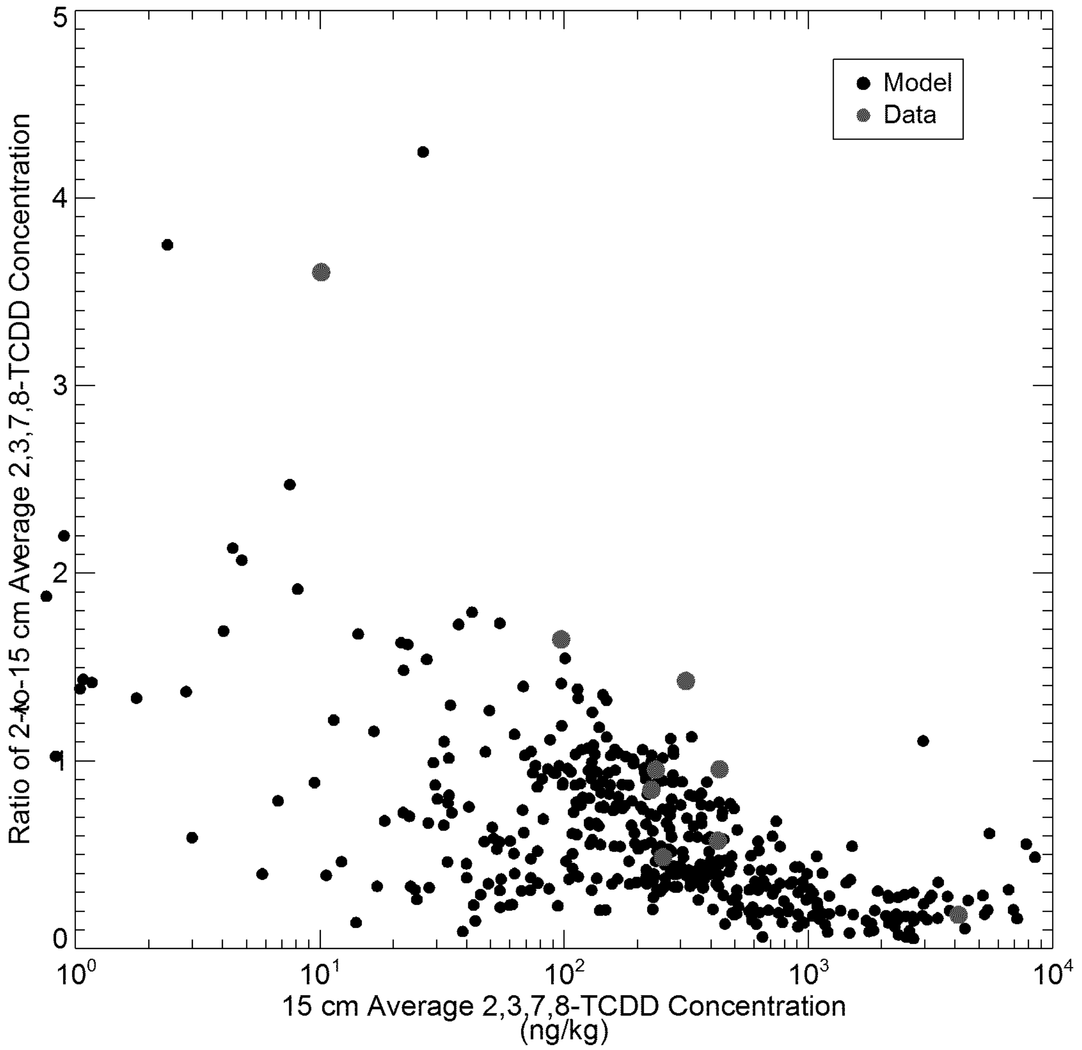

Figure 2a

Model Calculated and Measured 2 cm and 15 cm Average Concentration Ratio
Versus 15 cm Average Concentration for 2,3,7,8-TCDD
Exposure Depth Dispute Resolution

Model run: LPR_long_1410-34
Model 2 cm concentrations computed as length-weigthed averages of top 2 layer results
Model results were averaged annually from WY0809 within RM0-14. Ratio computed from averaged concentrations.

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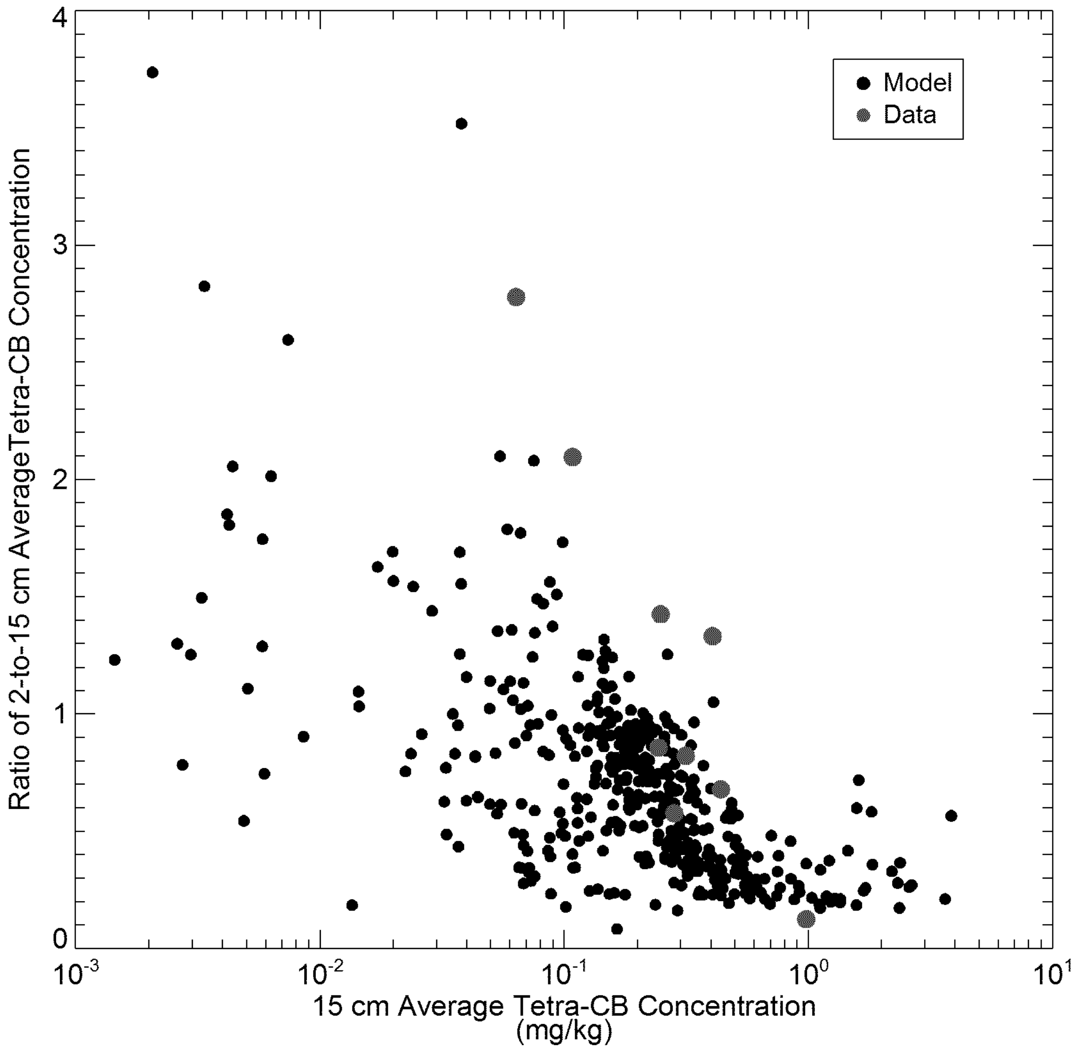

Figure 2b

Model Calculated and Measured 2 cm and 15 cm Average Concentration Ratio
Versus 15 cm Average Concentration for Tetra-CB
Exposure Depth Dispute Resolution

Model run: LPR_Tetra_long_1410-07
Model 2 cm concentrations computed as length-weigthed averages of top 2 layer results
Model results were averaged annually from WY0809 within RM0-14. Ratio computed from averaged concentrations.
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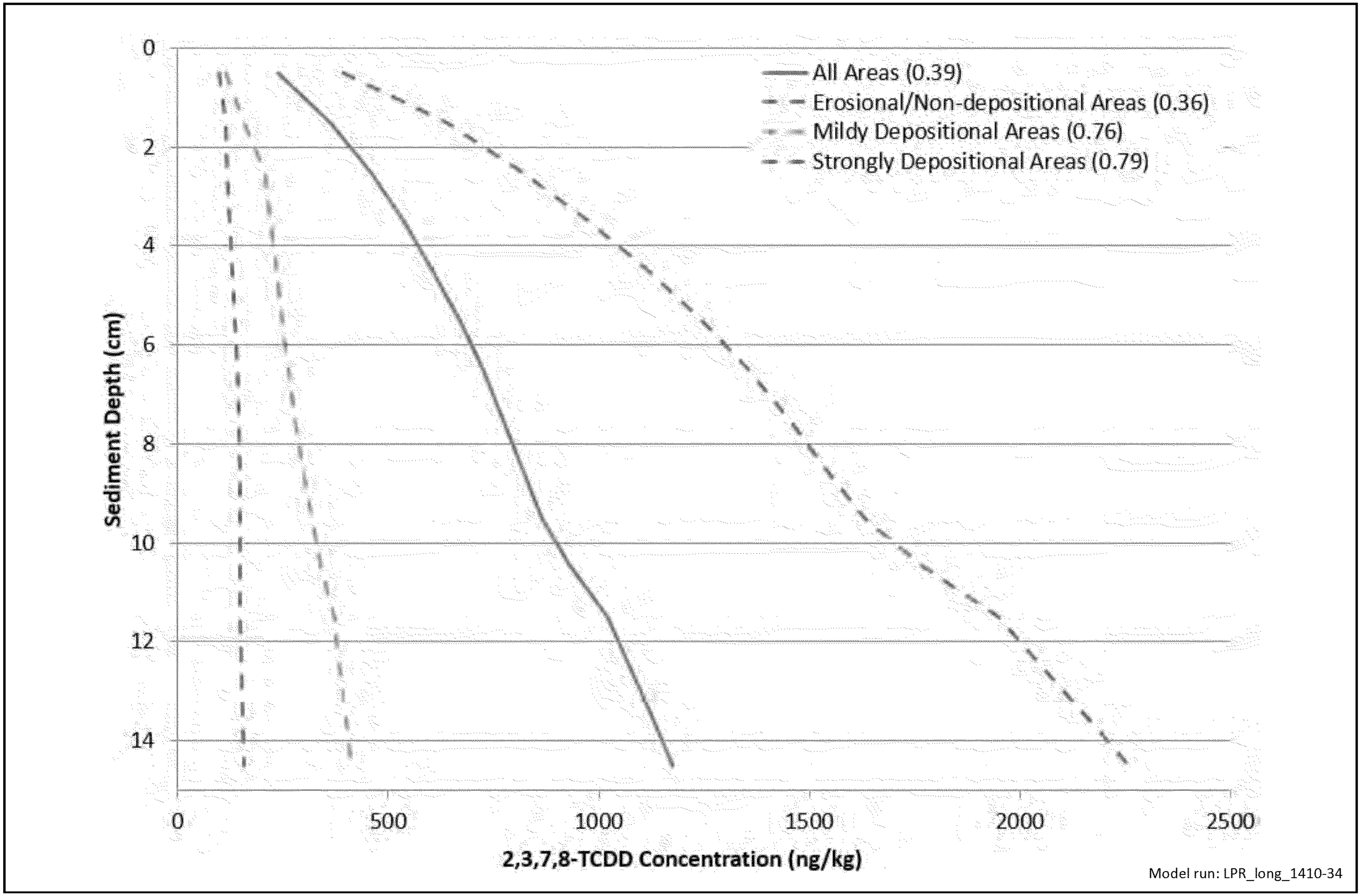


Figure 3a
Vertical Profiles of Model Calculated Average 2,3,7,8-TCDD Concentration in RM 0-8 at the End of WY 2010
Exposure Depth Dispute Resolution
Sediment layer 1 shown as 1 cm for plotting purposes. Values posted in the legend represent 2 cm to 15 cm average concentration ratios.

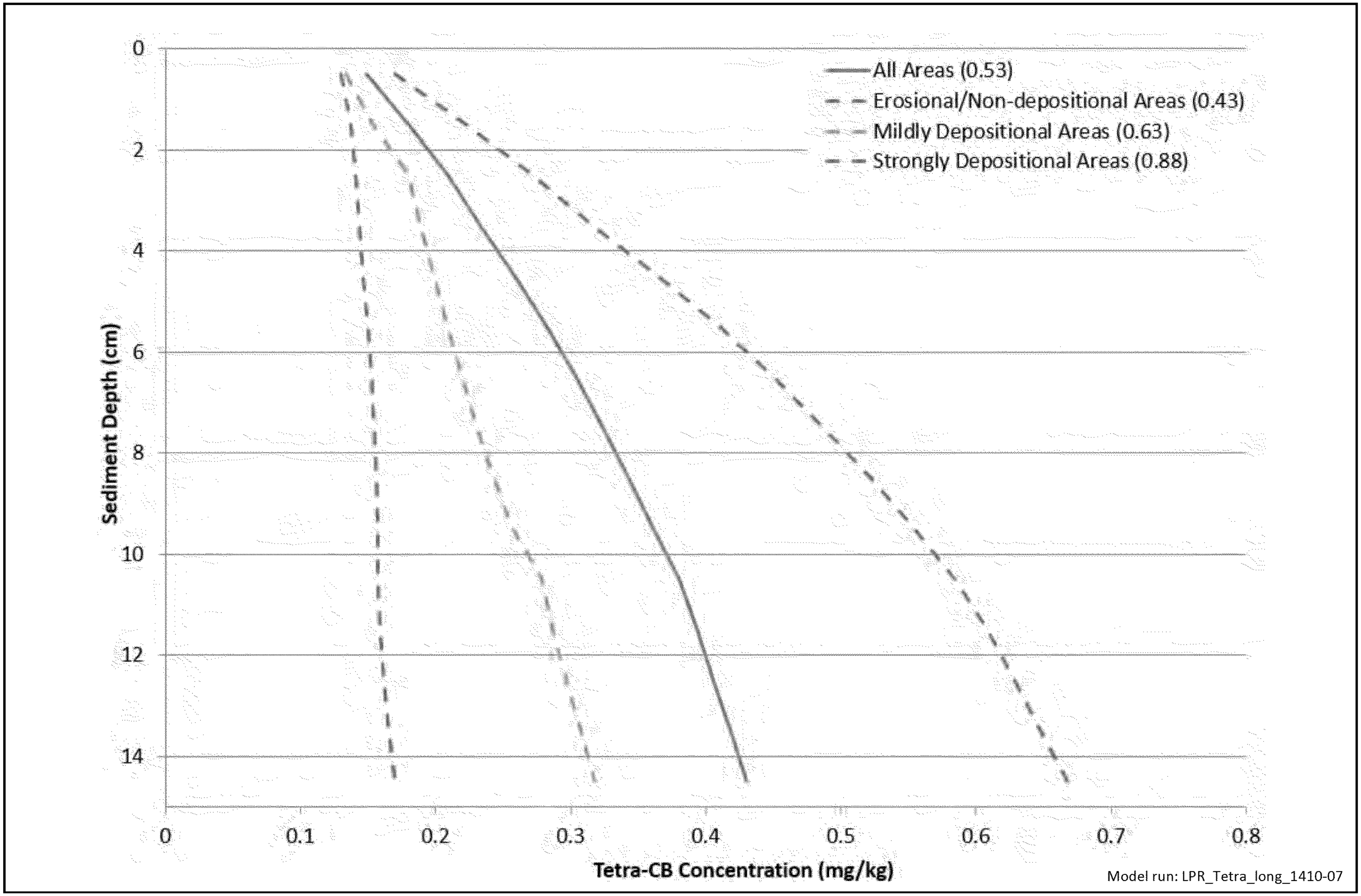


Figure 3b
Vertical Profiles of Model Calculated Average Tetra-CB Concentration in RM 0-8 at the End of WY 2010
Exposure Depth Dispute Resolution
Sediment layer 1 shown as 1 cm for plotting purposes. Values posted in the legend represent 2 cm to 15 cm average concentration ratios.

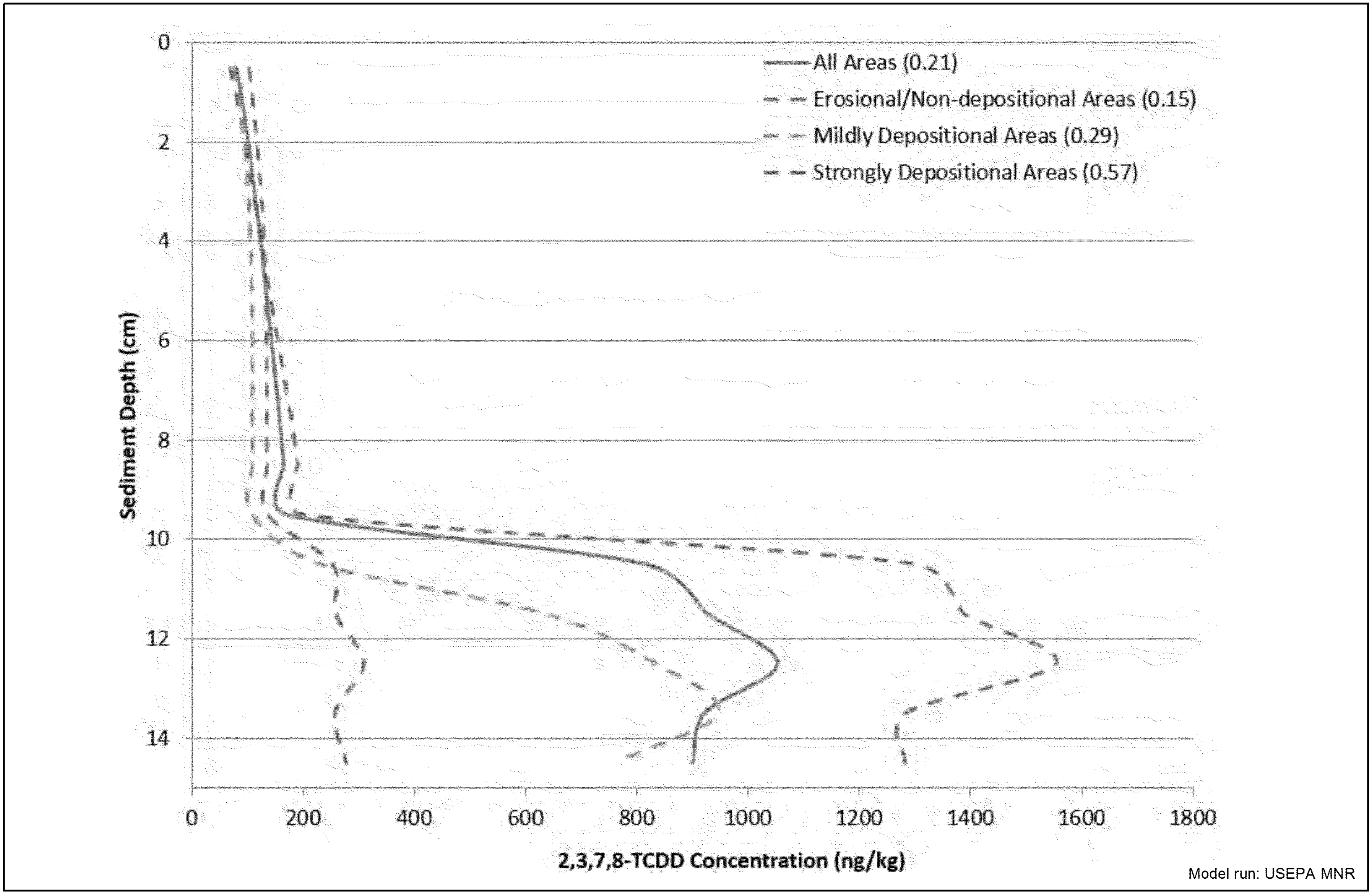


Figure 4a

Vertical Profiles of Region 2 FFS Model Calculated Average 2,3,7,8-TCDD Concentration in RM 0-8 at the End of WY 2010

Exposure Depth Dispute Resolution

Sediment layer 1 shown as 1 cm for plotting purposes. Values posted in the legend represent 2 cm to 15 cm average concentration ratios.

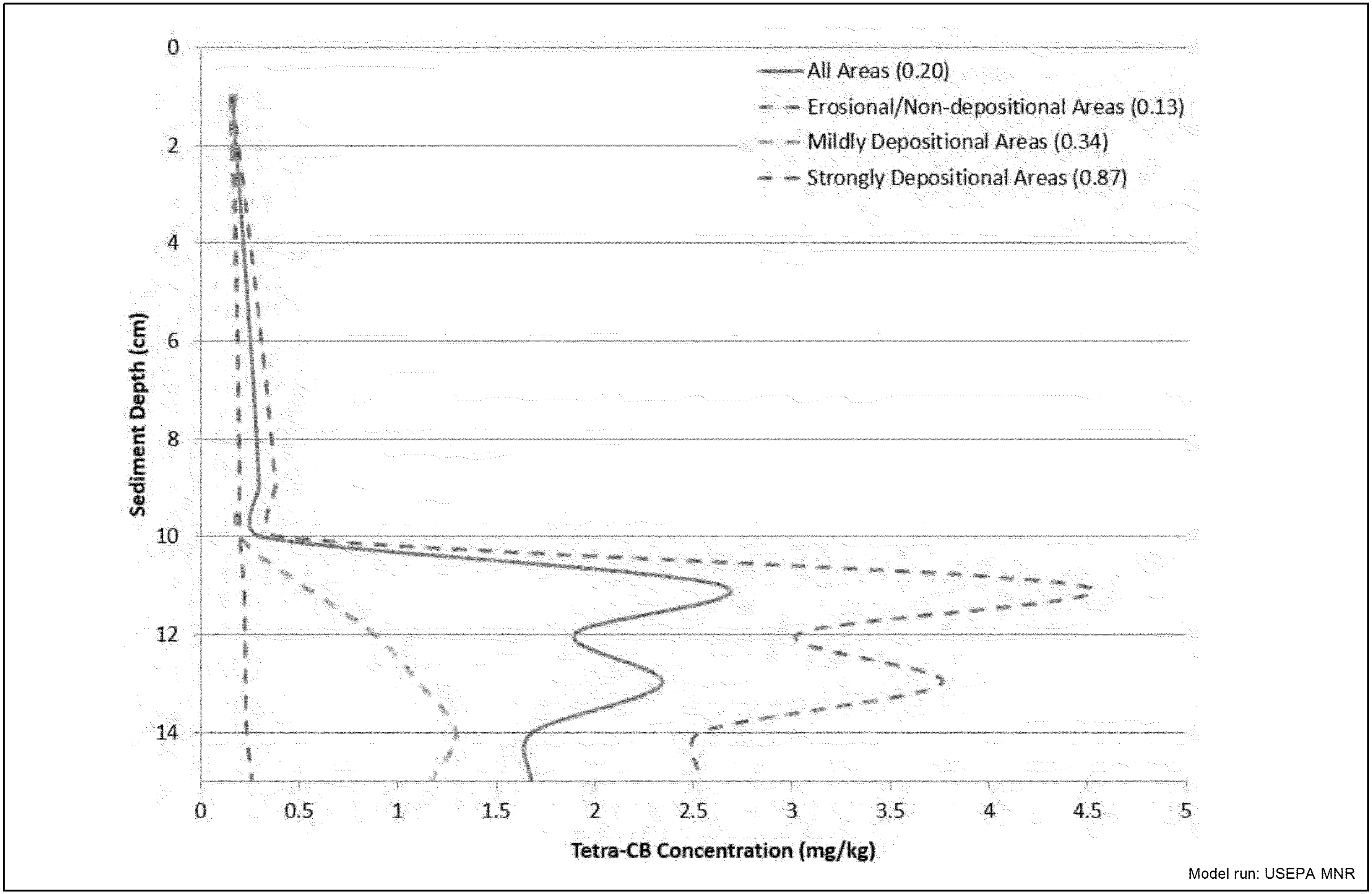
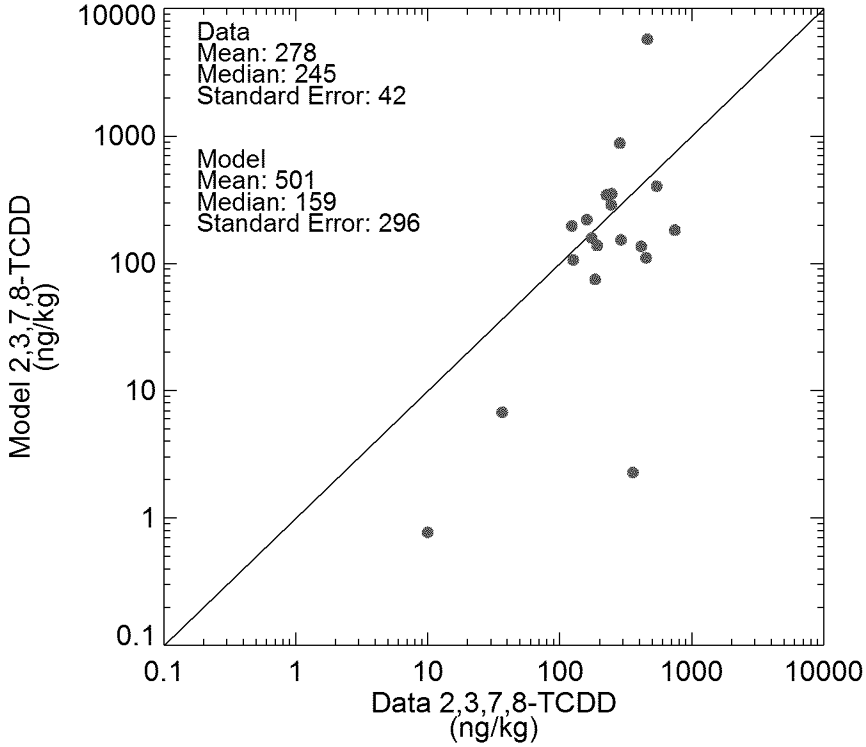


Figure 4b

Vertical Profiles of Region 2 FFS Model Calculated Average Tetra-CB Concentration in RM 0-8 at the End of WY 2010

Exposure Depth Dispute Resolution

Sediment layer 1 shown as 1 cm for plotting purposes. Values posted in the legend represent 2 cm to 15 cm average concentration ratios.



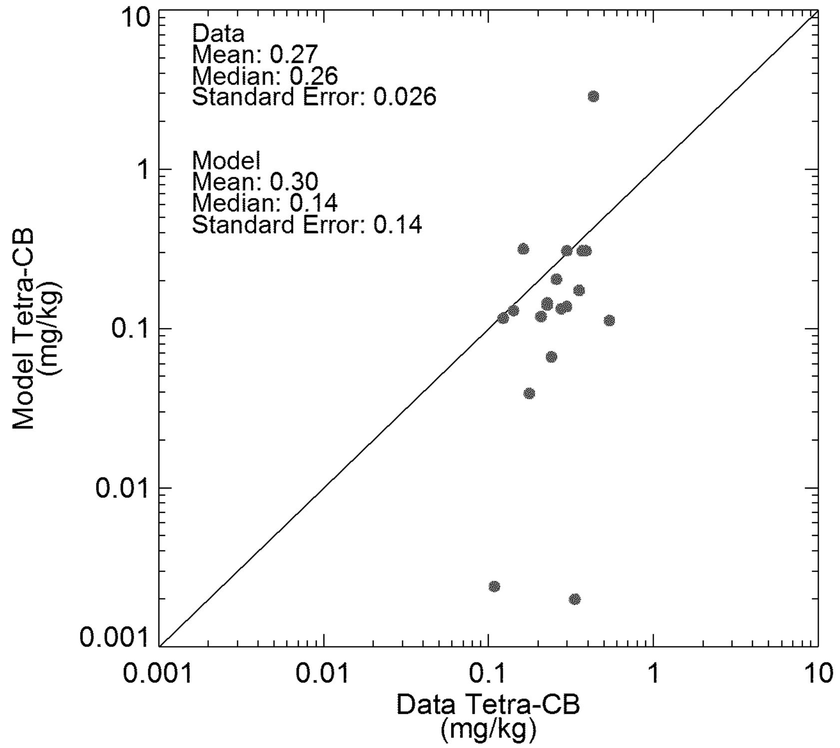


Figure 5

Model Calculated Versus Measured 2 cm Concentration for 2,3,7,8-TCDD and Tetra-CB
Exposure Depth Dispute Resolution

Model results are matched to the closest sample collection time.
Model 2 cm concentrations computed as length-weigthed averages of top 2 layer results
Eight Region 2 selected CPG finely segmented cores, nine 2007 USEPA EMBM cores,
and two cores from 2007-2008 sediment sampling program are shown.
TCDD model run: LPR_long_1410-34. Tetra-CB Model Run: LPR_Tetra_long_1410-07

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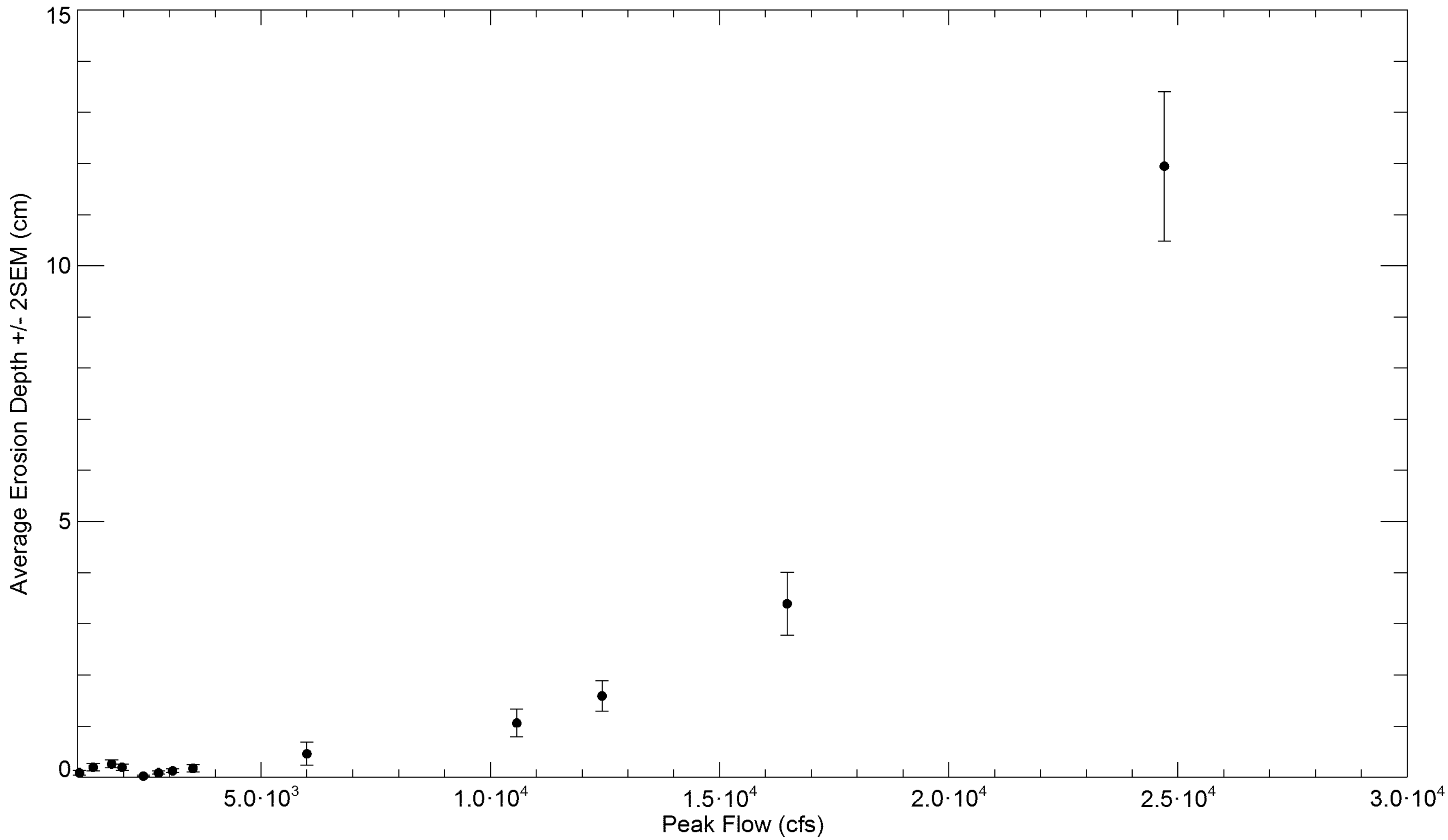

Figure 6

Average Erosion Depth Over Cells Experiencing Erosion by High Flow Events
Exposure Depth Dispute Resolution

Results were analyzed from 12 of the calibration years.

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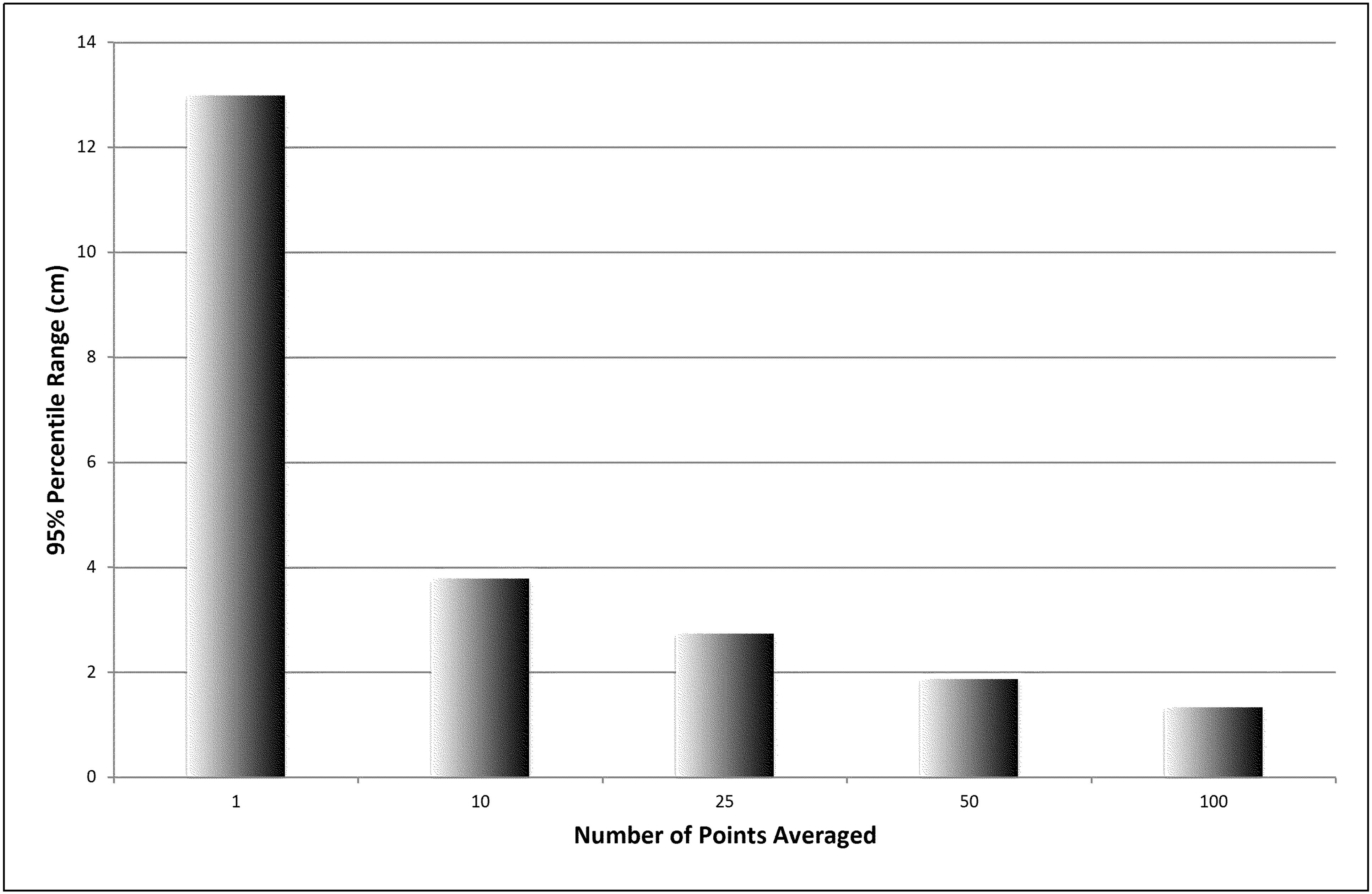

Figure 7
Illustration of Decrease in Uncertainty as a Result of Averaging Larger Numbers of Individual Measurements
Exposure Depth Dispute Resolution

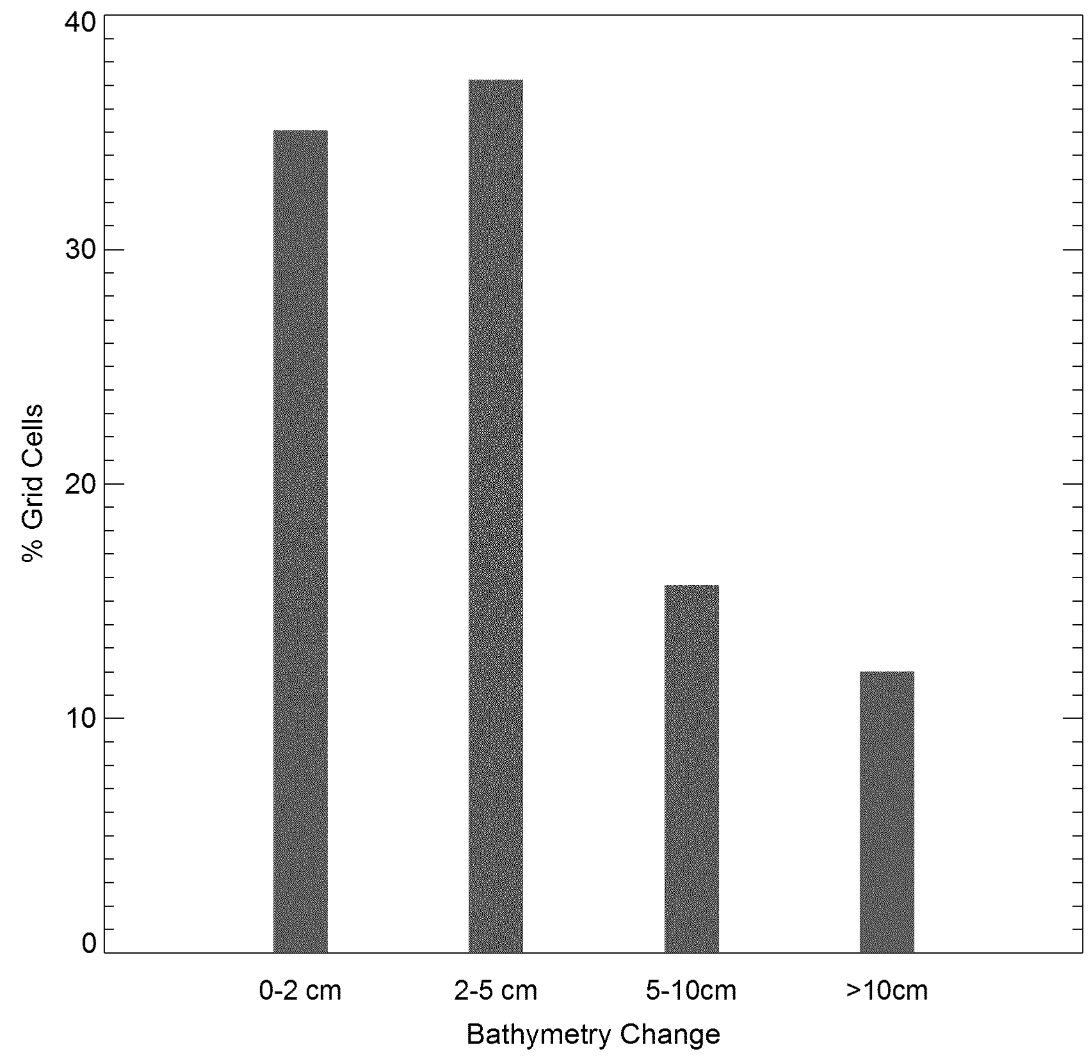

Figure 8

Frequency Distribution of Measured Bathymetric Changes Between WY 2007 and 2008

Exposure Depth Dispute Resolution

Source: Modified plotting from Figure 67 from Appendix M of the RI report (Anchor QEA et al. 2015).
Bathymetry data averaged over grid cells.

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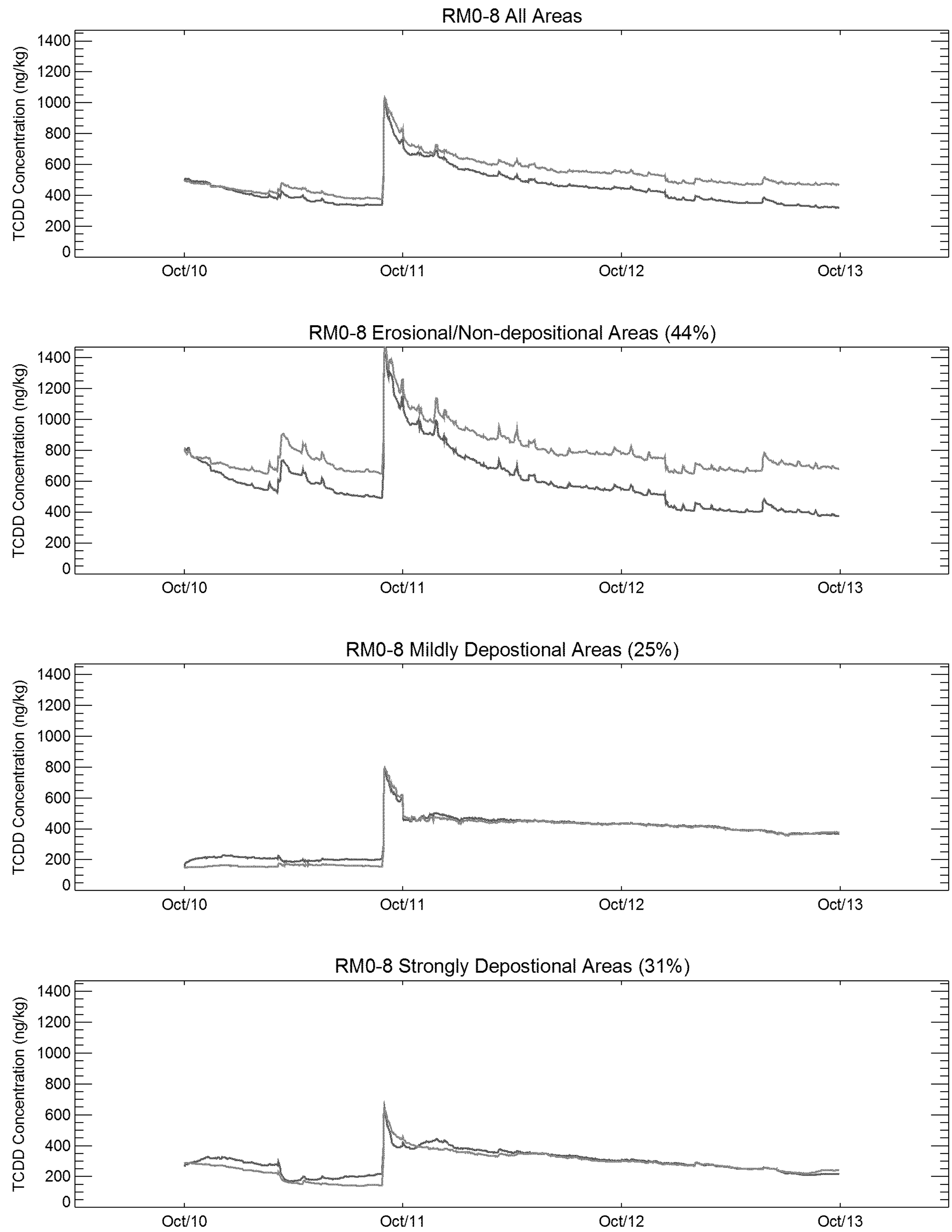

Figure 9

Model Sensitivity Results of 2 cm Sediment 2,3,7,8-TCDD Concentrations in LPR during WY 2011-2013

Exposure Depth Dispute Resolution

Fluff Sensitivity Run 1

Base Run

Fluff Sensitivity Run 1: Same as base run except kc=0.15 and kf=5000k.

CF - \\nereus\D_Drive\Projects\Passaic_CPG\MODEL\METRICS\Calib_bed_08_817_temporal_v2_140507.pro
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Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit J

NITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
290 BROADWAY
NEW YORK, NEW YORK 10007-1866

November 19, 2015

BY ELECTRONIC MAIL

Robert Law, Ph.D.
demaximis, inc.
186 Center Street, Suite 290
Clinton, New Jersey 08809

Re: Lower Passaic River Study Area, 17-Mile RI/FS
Benthic Community Exposure Depth

Dear Dr. Law:

This will respond to your letter dated November 13, 2015. Your letter provides the Dispute Resolution Statement of the Lower Passaic River Cooperating Parties Group (CPG) and addresses EPA's query whether to extend the informal Negotiation Period under Paragraph 64 of the Administrative Settlement Agreement and Order on Consent (AOC) for the Remedial Investigation and Feasibility Study.

Although the letter states, on the final page, that the CPG believes that "site-specific exposures zone(s) could be resolved if the Region was willing to engage in a series of meaningful and substantive face-to-face meetings" this is belied by the rest of the letter, which substantially mischaracterizes both EPA's already-extensive engagement with the CPG on this issue and EPA's technical position.

EPA will review the Dispute Statement provided by the CPG and evaluate if there is any basis for further discussions. If there is, we will schedule a meeting at the earliest mutually convenient time.

If the Dispute Statement shows that there is no utility in further discussions, we will develop a statement of position on behalf of the Lower Passaic River team, with input from the Partner Agencies (New Jersey Department of Environmental Protection, U.S. Fish & Wildlife Service, and National Oceanic and Atmospheric Administration), to provide to Walter Mugdan, the dispute decision maker for EPA.

We will let your know in early December 2015 how we intend to proceed.

Sincerely,

Stephanie Vaughn, Project Manager
LPRSA 17-Mile RI/FS

cc: R. Basso
W. Mugdan, EPA
S. Flanagan, EPA
W. Hyatt, CPG

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit K

NITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION II
290 BROADWAY
NEW YORK, NEW YORK 10007-1866

January 13, 2016

BY ELECTRONIC MAIL

Robert Law, Ph.D.
de maximis, inc.
186 Center Street, Suite 290
Clinton, New Jersey 08809

Re: Lower Passaic River Study Area (LPRSA) Administrative Settlement Agreement and Order on Consent for Remedial Investigation/Feasibility Study, CERCLA Docket No. 02-2007-2009 - Benthic Community Exposure Depth

Dear Dr. Law:

On behalf of the U.S. Environmental Protection Agency (EPA), this is to follow up on EPA's letter dated November 19, 2015 and further respond to your letter dated November 13, 2015. Your letter provided the Dispute Resolution Statement of the Lower Passaic River Cooperating Parties Group (CPG) and addressed EPA's query whether to extend the informal Negotiation Period under Paragraph 64 of the Administrative Settlement Agreement and Order on Consent (AOC) for the Remedial Investigation and Feasibility Study.

Having reviewed the Dispute Statement, we have concluded that the most productive path forward at this time is to end the Negotiation Period and submit this matter to Walter Mugdan, the Director of the Emergency and Remedial Response Division (ERRD), who will be the decision-maker in this dispute since the position of Strategic Integration Manager within Region 2 ERRD no longer exists. EPA staff will prepare a written statement for Mr. Mugdan's review, which we will forward to you.

Please let me know if you have any questions.

Sincerely,

Jennifer LaPoma

Jennifer LaPoma, Remedial Project Manager
Lower Passaic River Study Area RI/FS

Dispute Resolution Proceeding Pursuant to Administrative Settlement Agreement and Order on Consent for Remedial Investigation and Feasibility Study, US EPA Region 2 CERCLA Docket No. 02-2007-2009

EPA Region 2 Staff Statement of Position

June 2016

Exhibit L

de maximis, inc.

186 Center Street
Suite 290
Clinton, NJ 08809
(908) 735-9315
(908) 735-2132 FAX

January 28, 2016

Jennifer LaPoma
17-mile LPRSA RI/FS Remedial Project Manager
U.S. Environmental Protection Agency, Region 2
290 Broadway
New York, NY 10007-1866

Via Electronic Delivery

Re: ***Lower Passaic River Study Area (LPRSA)-Exposure Depth/Zone Dispute Resolution-***
(1) Supplement to the CPG's November 13, 2015 Exposure Depth Dispute Resolution Statement
(2) Response to Region 2's January 13, 2016 Letter
May 2007 Administrative Agreement and Order on Consent for Remedial Investigation/Feasibility Study – CERCLA Docket No. 02-2007-2009 (AOC)

Dear Ms. LaPoma:

The Lower Passaic River Cooperating Parties Group (CPG) is providing USEPA Region 2 (Region 2) supplemental information to its Dispute Resolution Statement as part of the CPG's June 12, 2015 invocation of dispute resolution pursuant to paragraph 64 of the May 2007 Administrative Order on Consent. The CPG acknowledges Region 2's decision to proceed with a formal dispute resolution process outlined in its January 13, 2016 letter; however, the CPG believes that the supplemental information presented in this letter is sufficient for the Region to reconsider its decision and restart the negotiation period.

The USEPA Office of Research and Development recently published guidance on determining the biologically relevant sampling depth for terrestrial and aquatic ecological risk assessments (Determination of the biologically relevant sampling depth for terrestrial and aquatic ecological risk assessments. EPA/600/R-15/176; Attachment). For aquatic environments, EPA's guidance document provides:

- a definition of what constitutes the biologically active zone (BAZ),
- a summary of literature searches on the depth of the BAZ in different types of aquatic environments, and
- a recommended method for determining a site-specific BAZ.

The EPA guidance document defines the BAZ as the depth from the sediment surface within which 80% of the benthic organisms are found (based on abundance measurements). It also presents an alternative using 80% of the biomass as the metric, but correctly notes that this metric can be significantly skewed by the presence of a single large organism (e.g., single bivalve at depth). Figure 3 of EPA's guidance summarizes the results of the literature search showing that the BAZ (80% abundance) is around 10 cm or less in most habitats.

Habitat in the LPRSA, based on the sediment type and salinity factors the guidance document considered relevant to defining the BAZ, is largely mud, sand, and mixed mud and sand (Figure – attached for your reference). For these types of habitats, the guidance document suggests that the BAZ will generally be 10 cm or less. The findings presented in the EPA guidance document are consistent with the LPRSA findings based on the interpretation of Sediment Profile Imaging (SPI) survey images in which biological activity rarely appeared to extend beyond the upper several cm of sediment (Germano & Associates 2005), which the guidance document would round up to 5 cm.

The subject of the current dispute between the CPG and Region 2 is the depth of the exposure zone (EZ), a subset of the BAZ where the majority of the benthic organisms serving as a food source for benthic feeding fish are located. Based on the findings presented in EPA's guidance, as well as LPRSA site-specific data, the CPG's conclusion that the BAZ is generally less than 10 cm is well-founded. In 2015, the CPG presented Region 2 with a scope of work designed to further examine the depth of the EZ in the LPRSA. The CPG's sampling collection design is consistent with the methods described in the guidance document (see attached Table), including the collection of salinity and sediment grain size distribution data to allow data interpretation by habitat type.

EPA's guidance provides a clear path forward to resolving the dispute and developing site-specific exposure depth(s) for the entire 17-mile LPRSA. This path could include the following:

1. The existing site-specific data (i.e., SPI, sediment type and salinity) collected as part of the 17-mile Remedial Investigation and depicted in the attached Figure provide an interim map of exposure depths following consultation and review with Region 2.
2. The interim map can be validated and updated using data collected as part of a field sampling program based on the EPA sampling protocol (Table) which the CPG is willing to implement in Spring 2016 under Region 2 oversight.

The CPG is encouraged by the recent EPA guidance and hopes that Region 2 will consider it as a reasonable approach to develop site-specific exposure depths for the entire 17-mile LPRSA. As such, the CPG proposes that Region 2 reconsider its decision to end the negotiation period for the Exposure Depth Dispute Resolution and instead engage in a series of technical meetings to develop a 17-mi LPRSA BAZ and Exposure Depth map and sampling program for Spring 2016.

The CPG requests that Region 2 include this letter and attachments into the Administrative Records for the 17-mile LPRSA operable unit of the Diamond Alkali Superfund Site and the Region's 8-mile FFS and Proposed Plan.

Please contact Bill Potter or me with any questions or comments.

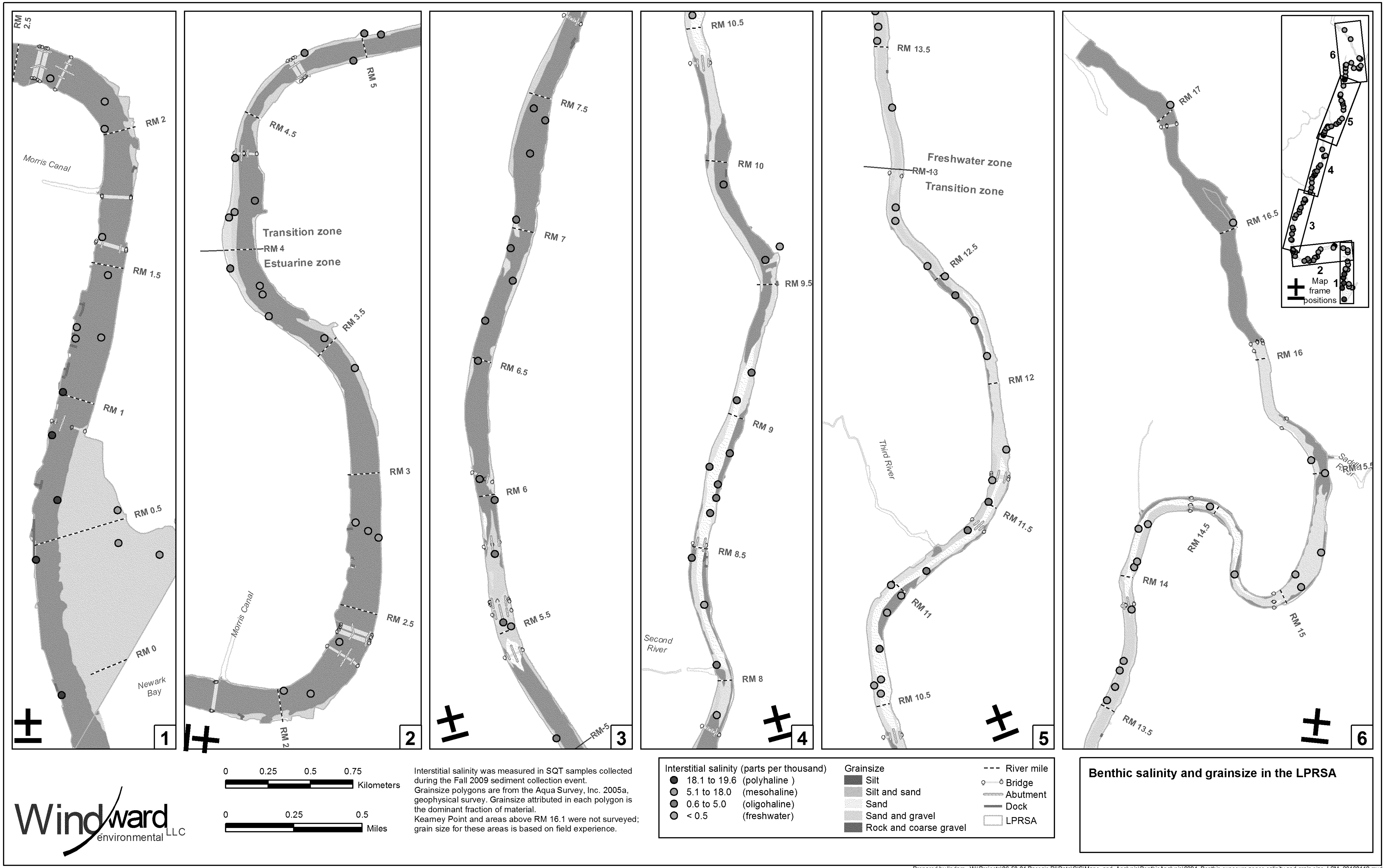
Very truly yours,

de maximis, inc.

Robert H. Law, PhD
CPG Project Coordinator

Figure and Table
Attachment - Determination of the biologically relevant sampling depth for terrestrial and aquatic ecological risk assessments. EPA/600/R-15/176

cc: Stephanie Vaughn, USEPA Region 2
Ray Basso, USEPA Region 2
Walter Mugdan, USEPA Region 2
Sarah Flanagan, USEPA Region 2
James Woolford, USEPA HQ
Steve Ells, USEPA HQ
Marc Greenberg, USEPA ERT-East
CPG Members
William Hyatt, CPG Coordinating Counsel
Willard Potter, CPG Project Coordinator



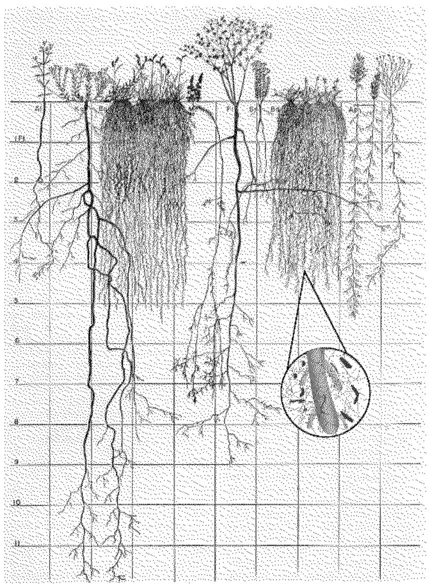
Prepared by lindam , W:\Projects\06-58-01 Passaic RI\Data\GIS\Maps_and_Analysis\BenthicAnalysis\6294_Benthic exposure zones salinity and grain size_LSM_20160112.mxd

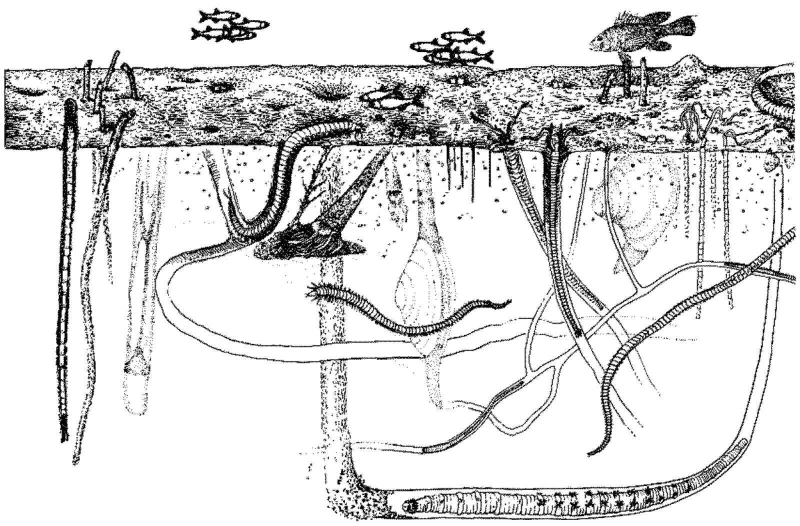
Table - Comparison of EPA (2015) sampling method with proposed CPG sampling method to define the depth of biological activity

EPA 2015 Sampling Method	CPG's 2015 Sampling Method
Collect sediment sample and subdivide by discrete depth horizons (e.g., 0-5 cm, 5-10 cm, 10-15 cm)	Collect sediment sample and subdivide by discrete depth horizons (e.g., 0-2 cm, 2-5 cm, 5-10 cm, 10-15 cm
Collect sediment sample using box corer or other suitable gear	Collect sediment sample by subsampling a van Veen grab sample using coring tubes
Enumerate abundance of benthic organisms by discrete depth interval	Enumerate abundance of benthic organisms by discrete depth interval
Collect data on salinity and sediment grain size distribution to define habitat type	Collect data on salinity and sediment grain size distribution to define habitat type
Define BAZ as depth from surface at which 80% of the total abundance has been counted	Define EZ as depth from surface at which 75% of the total abundance has been counted

EPA/600/R-15/176
ERASC-015F
October 2015

DETERMINATION OF THE BIOLOGICALLY RELEVANT SAMPLING DEPTH FOR TERRESTRIAL AND AQUATIC ECOLOGICAL RISK ASSESSMENTS





Ecological Risk Assessment Support Center
National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH

NOTICE

This document has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Cover art on left-hand side is an adaptation of illustrations in two Soil Quality Information Sheets published by the USDA, Natural Resources Conservation Service in May 2001: 1) Rangeland Sheet 6, Rangeland Soil Quality—Organic Matter, and 2) Rangeland Sheet 8, Rangeland Soil Quality—Soil Biota.

Cover art on right-hand side is an adaptation of an illustration from Life in the Chesapeake Bay, by Alice Jane Lippson and Robert L. Lippson, published by Johns Hopkins University Press, 2715 North Charles Street, Baltimore, MD 21218.

Preferred Citation:
U.S. EPA (U.S. Environmental Protection Agency). 2015. Determination of the Biologically Relevant Sampling Depth for Terrestrial and Aquatic Ecological Risk Assessments. National Center for Environmental Assessment, Ecological Risk Assessment Support Center, Cincinnati, OH. EPA/600/R-15/176.

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
Eh	redox potential
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ERAF	Ecological Risk Assessment Forum
ERASC	Ecological Risk Assessment Support Center
IT	intertidal
LCL	lower confidence limit
NCEA	National Center for Environmental Assessment
NOAA	National Oceanographic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
ORD	Office of Research and Development
PLFA	phospholipid fatty acids
SD	standard deviation
ST	subtidal
UCL	upper confidence limit
USDA	U.S. Department of Agriculture

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---

[1] Permanent Address: Air Force Center for Engineering and the Environment (AFCEE), Technical Support Division, San Antonio, TX.

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Assessment [ORD/NCEA]) and Mark Sprenger (EPA Emergency Response Team Region 2). David Farrar of EPA/ORD/NCEA provided useful comments on the manuscript. Amy Prues, Dan Heing and other members of ECFlex, an EPA contractor, provided technical support under contract EP-C-06-088. Programmatic review was conducted by Katie Matta (EPA Region 3) and Marc Greenberg (EPA Emergency Response Team Region 2), both Trichairs of EPA's Ecological Risk Assessment Forum. This document was externally peer reviewed under contract to Versar Inc., 6850 Versar Center, Springfield, VA 22151 (contract EP-C-07-025).

EXECUTIVE SUMMARY

Ecological risk assessors are frequently faced with the challenge of defining the biologically active zone, or "biotic zone," in soils and sediments during the design and interpretation of soil and sediment sampling programs. Knowledge of the biotic zone is necessary when evaluating sediment/soil concentrations, calculating risks to ecological receptors, and attempting to delineate the relevant depth for remediation at sites where an action is needed. As current practice with regards to determining the biotic zone is quite varied, EPA's Ecological Risk Assessment Forum (ERAF) submitted a request to Office of Research and Development (ORD)'s Ecological Risk Assessment Support Center (ERASC) to develop a scientifically defensible definition for the depth of the biotic zone in soils and sediments (see Appendix). In response to the ERAF request, the present document attempts to provide defensible approximations for what the depth of the biotic zone is within certain environments. Actual sampling depths may be modified by the assessor based on the purpose of the assessment. The primary audience for this document is Superfund staff and contractors, and ecological risk assessors, though general ecologists should find the information useful as well. The methods used in this study differ somewhat between Part 1 (Terrestrial Biotic Zone) and Part 2 (Aquatic Biotic Zone). In Part 1, biological activity was quantified in forests and grasslands as a function of depth across selected metrics. In Part 2, the biotic zone(s) in various habitats was based on the 80th percentile of abundance or biomass depth distributions. Part 1 has also been summarized in Anderson et al., (2010).

Part 1 (Terrestrial Biotic Zone) of this study uses a meta-analysis approach to quantify the zone of highest biological activity for soil-dwelling ecological receptors commonly utilized in ecological risk assessments (ERAs). Endpoints evaluated include: invertebrate density, microbial biomass carbon (C), microbial density, mycelium production, root biomass, root production and total phospholipid fatty acids (PLFA). Results suggest sampling strategies should be adaptive allowing for variable depths. If constant depths *are* utilized, our results suggest that samples should be collected to a depth of approximately 25−30 cm.

Part 2 (Aquatic Biotic Zone) explores data from a wide realm of habitat types in an attempt to develop habitat-specific practical default values for the depth of the biotic zone, where most organism-substrate interactions occur. We recommend that the depth of the biotic zone be based upon the 80th percentile of abundance or biomass depth distributions. The biotic zone, based on benthic abundance, in most estuarine and tidal freshwater environments is 10 or 15 cm. Exceptions are oligohaline and polyhaline mud (5 cm) and oligohaline sand (5 cm). In marine muds (both coastal and offshore), the biotic zone is 15 cm. In other marine substrates it is 10 cm (marine coastal mixed and marine offshore sand) or 5 cm (marine coastal sand). In lentic

environments, the biotic zone is 15 cm. The biotic zone tends to be deeper when biomass is taken into account. The biotic zone in lotic systems varies from 15 to 35 cm depending upon water/habitat type. In areas populated by a high density of deep dwelling organisms such as the examples provided, the biotic zone may be somewhat deeper than our recommended values.

1. PART 1. TERRESTRIAL BIOTIC ZONE

1.1. INTRODUCTION

Risk assessors are frequently faced with the challenge of defining the biologically relevant sampling depth or "biotic zone" in soils and sediments during the design and interpretation of ecological studies. This may have important implications when evaluating ecological risk and/or designing a remediation scenario. For example, contamination occurring in layers deeper than the zone where most organisms live or feed may not be relevant to assessing ecological risk. In essence, spatial and vertical co-occurrence of soil contamination and ecological receptors need to be considered to estimate risks. While methodologies have been proposed that focus on optimizing the spatial scale of sampling efforts (Hathaway et al., 2008; Taylor and Ramsey, 2005), sampling depths for ERAs are usually dictated by the vertical distribution of soil contamination (Singh et al., 2008) or default to a generic value. These approaches may not adequately reflect site-specific exposures to soil biota. The default sampling depth for estimating exposure of plants, as well as earthworms, to contaminants has been reported as the top 30 cm (Suter, 2007); the top 12 cm has also been recommended as a default sampling depth for estimating exposure of plants to metals (U.S. EPA, 2005). The purpose of this study is to use a meta-analysis of ecological literature to quantify the zone of highest biological activity for soil-dwelling ecological receptors, and to determine whether or not a default value for the biologically relevant (soil) sampling depth can be supported.

1.2. METHODS

1.2.1. DATA EXTRACTION

Nonagricultural literature was searched using the Academic Search Complete database. Journal articles were limited to primarily 2000 through 2009. An exception was made in the case of a recent summary paper that cites earlier studies (Briones et al., 2007). There were no restrictions on publication sources so long as they were peer-reviewed. The database was searched with iterative combinations of (1) the keyword "soil" (2) keywords to locate studies containing appropriate biological metrics and (3) keywords to locate studies examining the metrics at stratified depths. Literature searches were restricted to soil invertebrate, plant, and microbial endpoints. Specifically, endpoints evaluated include: invertebrate density, microbial biomass carbon (C), microbial density, mycelium production, root biomass, root production and total PLFA. Studies were further restricted to those with data extractable from a table or a readable graph, reporting the depth for the top and bottom of each sample observation.

A categorical variable that refers to the dominant matrix vegetation at each site was defined and referred to as the "environment type" (e.g., forest, grassland, desert, shrubland, etc.)

and was extracted via site descriptions in the articles. However, sufficient data ($n > 10$) only existed for forests and grasslands. Consequently, only data from forests and grasslands were included in the analyses and are summarized in Table 1, which includes the biological metric, environment type, and number of depth intervals for each study. Admittedly, grouping sites into categories defined by generalized classes of vegetation is an oversimplification of the complexity of natural systems. However, we default to broad scale patterns in ecological organization necessary for meta-analyses of biological processes using studies with highly variable environment conditions (Levin, 2005).

An additional categorical variable that refers to the climate at each study site was also determined and included in analyses. Climate type was determined in a Geographic Information System. First, the geographic locations of study sites were extracted via site descriptions in the articles. Each site was then mapped with the Köppen-Geiger climate classification data (Kottek et al., 2006) and assigned a climate type based on its placement on the map. The broadest Köppen-Geiger categories (e.g., tropical humid [equatorial], dry [arid], mild mid-latitude [warm temperate], severe mid-latitude [snow], and polar) were used.

1.2.2. STATISTICAL ANALYSIS

Primary objectives of data analyses were to quantify biological activity as a function of depth for the selected metrics. To facilitate these objectives, paired data were necessary. Consequently, the midpoint of each depth interval was calculated to relate to the corresponding metric value reported from that particular depth interval. Relationships between midpoint depths and biological metric values were subsequently evaluated.

Relationships were evaluated collectively across metrics. However, it was first necessary to scale observations. First, all data within a metric were converted to a standard unit. Standard units were determined as the unit that was most frequently reported within a metric. Subsequently, all data within a metric were standardized to a standard normal variable (mean = 0, standard deviation [SD] = 1) across depths, environment types, and climates because each metric produced values with unique units or a completely different range of values for the same unit. Standard normal variables are simply computed by subtracting off the mean and dividing by the standard deviation. The idea being that data from similar depths would produce similar standardized metric values (i.e., z scores) that fall reasonably close to one another on the standard normal probability distribution allowing observations to be evaluated for depth, environment type, and climate effects across metrics.

Trends between standardized metric values and midpoint depths followed an exponential decay pattern. Consequently, nonlinear regression with an exponential decay function was used to model relationships. Because standardized metric values contained both positive and negative values, a three parameter exponential decay function was utilized of the form:

$$y=(A+C)e^{Bx}+C \quad \text{(Eq. 1)}$$

where y is standardized metric value, A is the y-intercept, B is a slope parameter, and C is a scale parameter necessary because metric values contained both negative and positive values.

Preliminary analyses indicated that significantly ($\alpha = 0.05$) different trends occurred between grasslands and forests as determined by contrasting residual sums of squares for full (both forests and grasslands) and nested reduced (forests and grasslands separately) models (see Equation 1). Consequently, Equation 1 was fitted to data from forests and grasslands separately. Unique parameters were estimated for each environment type. Climate effects were subsequently evaluated by testing the residuals from Equation 1 for differences across climate types within each vegetation class by analysis of variance (ANOVA). Nonlinear regression was performed using PROC NLIN and ANOVA was performed using PROC GLM in SAS Version 9.2 for Windows.

1.3. RESULTS AND DISCUSSION

Common soil-dwelling receptor groups evaluated during ERAs consist of plants and invertebrates (U.S. EPA, 2005). Microbial endpoints can be impacted by environmental contaminants (Giller et al., 1998), but they are often considered too variable to provide utility as a basis for chemical-specific soil screening levels (U.S. EPA, 2005). However, abundance of microbial communities is tightly coupled with the quality (i.e., carbon:nitrogen ratio) of substrates and regulates essential nutrient (e.g., nitrogen) availability in soils (Friedel and Gabel, 2001). Thus, microbial endpoints affect other higher order endpoints through feedback loops and were considered essential to our objectives.

1.3.1. META-ANALYSIS RESULTS

Relationships between the standardized metric meta-data and their corresponding midpoint sampling depths are presented in Figure 1. Three-parameter exponential decay functions (see Equation 1) were fitted to meta-data for grassland and forests separately. Climate was not significant ($\alpha = 0.05$) and did not influence relationships. Parameter estimates and approximate confidence intervals are presented in Table 2. Both models were highly significant ($p < 0.0001$). Grasslands produced an exponential decay function with higher standard normal scores and a steeper slope indicating relatively higher values for each common metric (i.e., invertebrate density, mycelium production, and root biomass; see Table 1) and a faster rate of decline. However, both functions resulted in an asymptotic plateau at roughly 27 cm (see Figure 1).

Grassland soils contain greater amounts of organic matter than forest soils because of higher primary production rates at steady state with decomposition (Zak et al., 1994). In general, matrix vegetation in grasslands consists of perennial herbaceous plants with high root densities and receive relatively less precipitation (Saviozzi et al., 2001). This greatly suppresses microbial decomposition and allows for the accumulation of organic matter, which produces soils with darker surface horizons relative to forest soils (NRCS, 2003). As a result, soil biota are usually more productive in grasslands because they experience less carbon limitation (Zak et al., 1994), which is consistent with Figure 1.

1.3.2. RECOMMENDATION OF SAMPLING DEPTH

Soils are highly heterogeneous mixtures of inorganic and organic constituents. Complex, multi-trophic assemblages of organisms comprise the soil biology and inextricably interact with and feed back to the soil organic matter resulting in a zone of interdependent biological processes referred to as the rhizosphere. Microorganisms are essential to the rhizosphere through the development of stable organic compounds (i.e., humic substances) and the hierarchical structure of soil aggregates (Kandeler et al., 2001). Soil organic matter is responsible for giving the rhizosphere its characteristic darker color, which in general soil classification terms is referred to as the A horizon (NRCS, 2003). Soil organic matter provides a source of energy for microbial respiration, which in turn regulates essential plant nutrients (Luxhoi et al., 2006). Consequently, the A horizon, via the rhizosphere, provides the foundation to the food web for soil ecosystems and should contain the vast majority of biological activity.

Results from Figure 1 were compared to the average depth of soil horizons. Accordingly, a regional data set was obtained from the U.S. Department of Agriculture (USDA) National Resource Conservation Service (NRCS) Cooperative Soil Survey Program. Depths of dominant soil horizons (O, A, B, and C) were utilized, which were measured from 636 soil pedons (i.e., the smallest volume of material that can be called "soil") from around the conterminous United States. The database is freely available and can be accessed online at http://soils.usda.gov/survey/geochemistry/index.html. Only data from Alfisol (characteristic forest soil) and Mollisol (characteristic grassland soil) soil orders (i.e., the highest level of USDA classification) were evaluated (NRCS, 2003).

Figure 2 illustrates the average biologically relevant sampling depth. Mean horizon depths for both Mollisol and Alfisol soil orders are shown overlaid on the first derivatives of

Figure 1. Mollisol and Alfisol soil orders are characterized with mean A horizons that extend to 19.3 and 20.2 cm, respectively. First derivatives from Figure 1 reach an approximate minimum, on an absolute scale, at 27 cm, roughly consistent with the mean depth of A horizons, although depths associated with derivative values are midpoints of a sampling interval. However, standard deviations for mean A horizon depths for Mollisol and Alfisol soil orders are 19.4 and 53.6, respectively, suggesting the minimum (on an absolute scale) derivative value of 27 cm falls within error limits of the A horizon for both soil orders. Thus, a definitive conclusion of this study is that A horizons, although not necessarily all inclusive, represent the average biologically active zone, at least for the metrics evaluated. Hence, capturing the A horizon is paramount to accurately evaluating potential exposure of environmental contaminants to soil biota.

Soil development is rarely uniform and processes such as erosion and deposition can influence the vertical distribution of biological activity across landscapes. Sampling strategies where a constant depth is collected may not accurately reflect site-specific exposures of environmental contamination to the soil biota. Samples that either fail to capture the extent of, or exceed, the A horizon may not accurately represent contaminant exposure to soil biota, resulting in inaccurate risk estimates. The depth of horizontal soil horizons can vary across the landscape (Luxhoi et al., 2006), which may also confound ERAs that utilize a constant depth. Consequently, sampling strategies should be adaptive allowing for A horizons with variable depths. If constant depths *are* utilized, our results suggest that samples should be collected to a depth of approximately 25-30 cm (see Figure 2) as opposed to shallower depths.

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Table 1. Summary of Data Used in Meta-analysis

Reference	Biological Metric	Environment Type	N[a]
Allison et al. (2007)	total PLFA	grassland	6
Altesor et al. (2006)	root biomass	grassland	5
Borken et al. (2007)	root biomass	forest	24
Briones et al. (2007) (Review Article)			
Abrahamsen and Thompson (1979)	invertebrate density	forest	1
Chalupsky (1986)	invertebrate density	forest	1
Chiba et al. (1976)	invertebrate density	forest	1
Hutha (1984)	invertebrate density	forest	1
Kairesalo (1978)	invertebrate density	forest	1
Lundkvist (1982)	invertebrate density	forest	1
Lundkvist (1983)	invertebrate density	forest	1
Makulec (1983)	invertebrate density	forest	1
Nurminen (1967)	invertebrate density	forest	1
Phillipson et al. (1979)	invertebrate density	forest	1
Thambi and Dash (1973)	invertebrate density	grassland	1
Yeates (1986)	invertebrate density	grassland	1
Claus and George (2005)	root biomass	forest	33
Davis et al. (2007)	root biomass	grassland	5
Davis et al. (2007)	root biomass	forest	6
Kemmitt et al. (2008)	root biomass	grassland	1
Kemmitt et al. (2008)	root biomass	forest	6
Steinaker and Wilson (2008)	invertebrate density	grassland	5
Steinaker and Wilson (2008)	mycelium production	grassland	5
Steinaker and Wilson (2008)	root production	grassland	5
Steinaker and Wilson (2008)	invertebrate density	forest	5
Steinaker and Wilson (2008)	mycelium production	forest	4
Steinaker and Wilson (2008)	root production	forest	5
Tsai et al. (2007)	microbial density	forest	90
Zheng et al. (2005)	microbial biomass C	forest	7

[a]Number of observations. Each observation represents a discrete depth interval.

Table 2. Parameter Estimates and 95% Lower and Upper Confidence Intervals[a] (LCL and UCL, Respectively) for the Nonlinear Function (See Equation 1) Fit to Standardized Data for Both Forests and Grassland Environment Types

Environment Type	Parameter	95% LCL	Estimate	95% UCL
Forest	A	0.873	1.56	2.26
	B	−0.185	−0.0919	0.00127
	C	−0.527	−0.303	−0.0783
Grassland	A	2.32	4.89	7.47
	B	−0.295	−0.160	−0.024
	C	−1.12	−0.641	−0.162

[a]Confidence intervals for nonlinear functions are only approximate (Kutner et al., 2004).

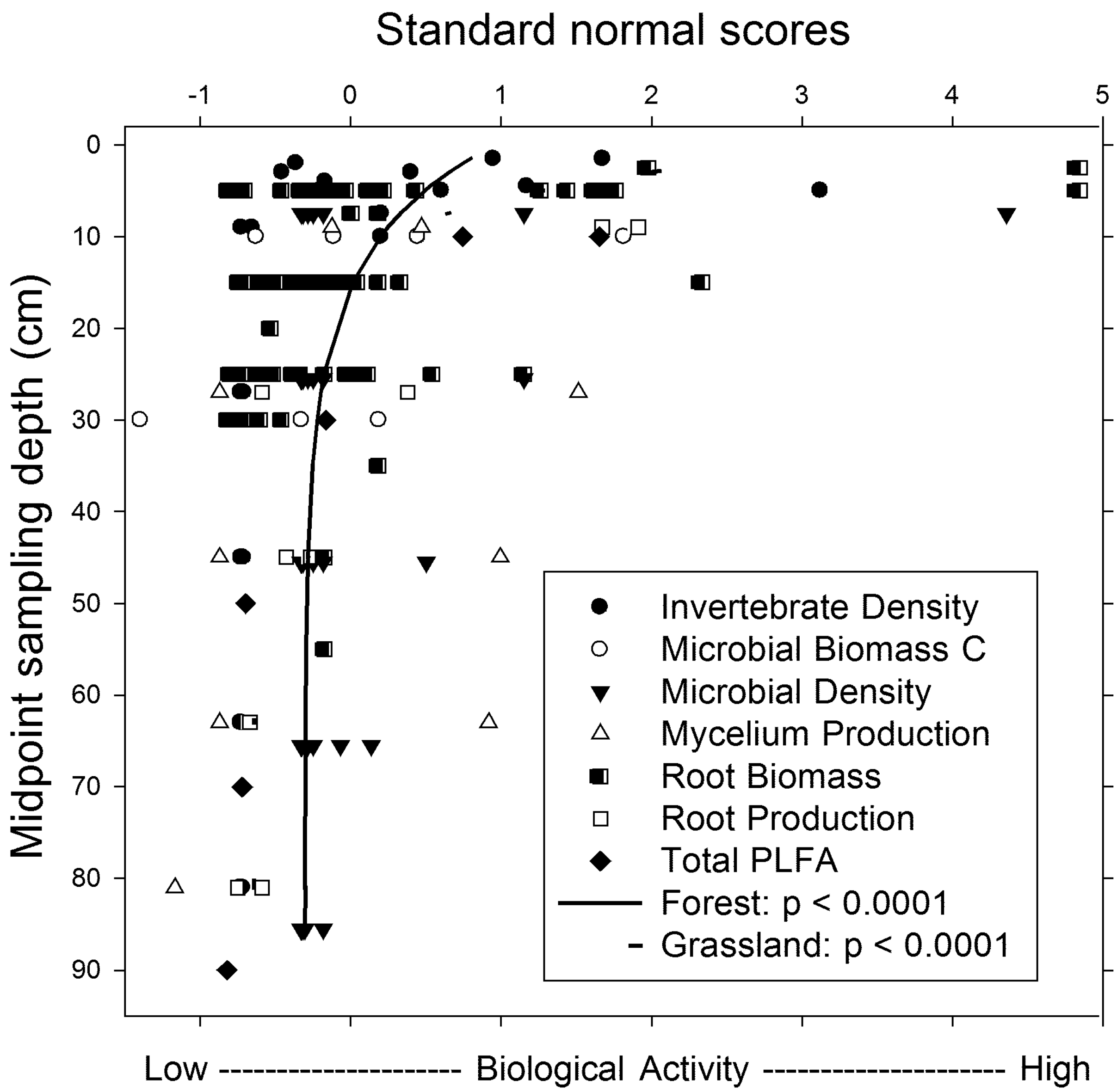

Figure 1. Nonlinear (see Equation 1) Relationships Between Standardized (mean = 0; SD = 1) Biological Metrics and Their Midpoint Sampling Depths for Forests and Grasslands.

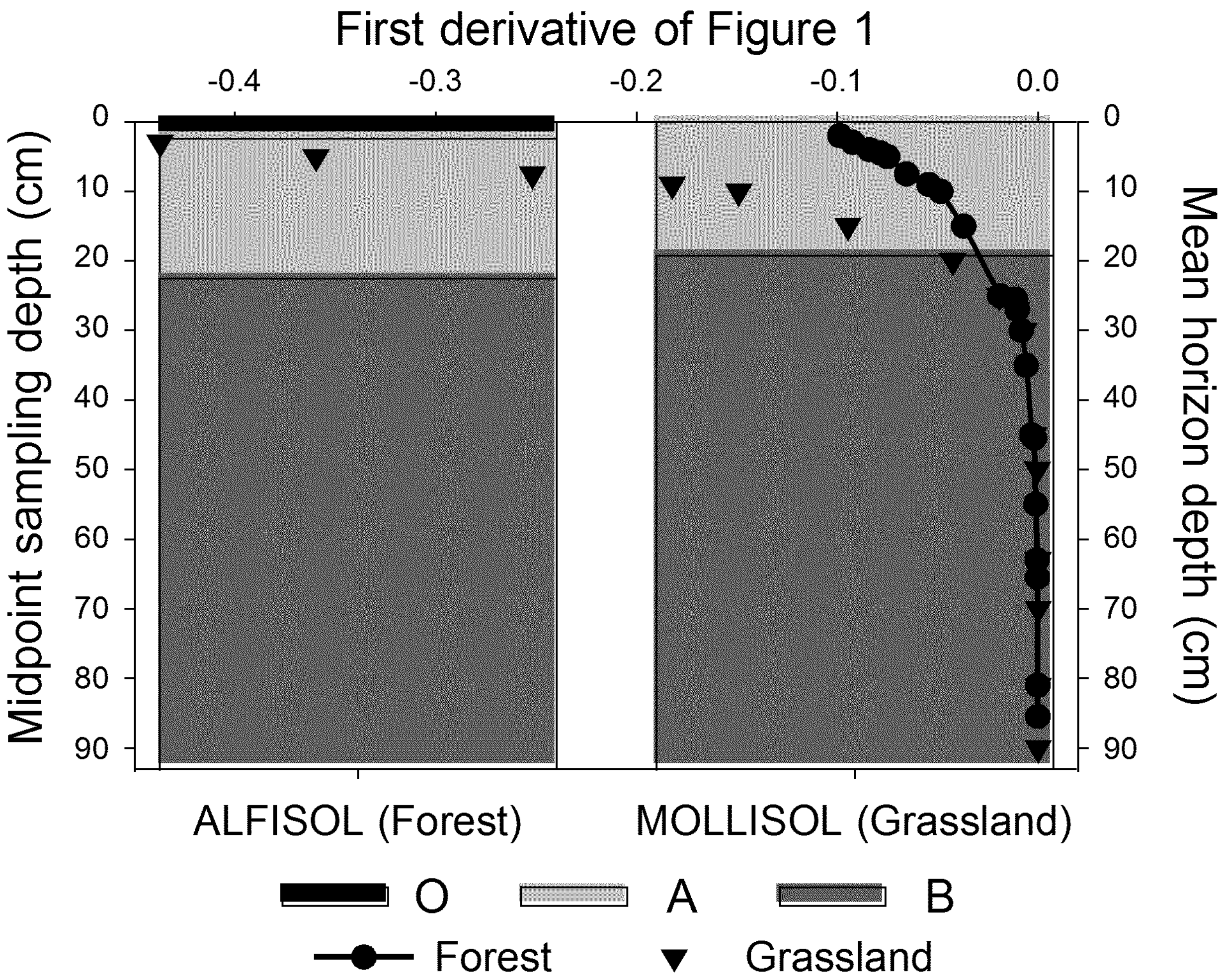

Figure 2. Illustration of the Average Biologically Relevant Sampling Depth. Mean soil horizon (O, A, and B) depths (determined from available data produced by the USDA/NRCS Cooperative Soil Survey) are summarized by the vertical bars. The first derivatives from the nonlinear functions, illustrated in Figure 1, reach a minimum (on an absolute scale) value (i.e., constant biological activity) at approximately the transition between the A and B soil horizons for the depths evaluated.

2. PART 2. AQUATIC BIOTIC ZONE

2.1. INTRODUCTION

Benthic organisms alter the fluxes of particulate and dissolved chemical species through their burrowing, ingestion and excretion, tube-building, and biodeposition activities (Thoms et al., 1995). Hence, the zone or area of the substrate where these organisms reside is important as a site of exchange for nutrients and contaminants, especially with overlying waters. The vertical extent of this zone is often referred to as the depth of bioturbation, or mixed layer. Thoms et al. (1995) compiled data on the depth of the mixed layer, mainly from radio-isotope tracer studies. Mixing depths ranged from less than 1 cm (Amazon continental shelf) to greater than 35 cm (e.g., deep Puget Sound). Based on radio-isotope tracer profiles from a large number of studies, Boudreau (1994) determined the mean (± SD) mixing depth worldwide to be 9.8 ± 4.5 cm. Based on tracer profiles, as well as sediment profile imaging literature and surveys, Teal et al. (2008) estimated the global mean (± SD) mixing depth to be 5.75 ± 5.67 cm. Other studies have utilized cores to determine the depth distribution of benthic invertebrates from specific locations around the world. Ecological risk assessors should consider the depth of this "biotic zone" in the design and interpretation of sediment sampling programs, as this is where exposure to contaminants or other stressors will occur. This zone is also the source of prey for benthic-feeding fishes (and shore birds in the intertidal) and, potentially, trophic transfer of pollutants.

Knowledge of the biotic zone is necessary when attempting to delineate the relevant depth for remediation at sites where an action is needed. When evaluating remedial alternatives in cases where contaminant hotspots extend deep within the sediment, it may not be prudent (for environmental and cost reasons) to consider zones deeper than where the bulk of organisms reside. In the case where contaminated sediments are capped with clean substrate, the thickness of the cap should exceed the depth to which infauna burrow, or the depth of the biotic zone, in order to avoid infiltration of contaminants through the cap and into the water column. The present paper explores data from a wide realm of habitat types in an attempt to develop habitat-specific practical default values for the depth of the biotic zone, where most organism-substrate interactions occur. We use the 80th percentile of abundance or biomass depth distributions as a common measure for comparison among samples. In our judgement, use of the "80th percentile" strikes a balance by including most of the organisms, but without going to depths where the biota are very sparse. We acknowledge a degree of subjectivity in choosing this value, but note that a number of assessment programs (National Oceanographic and Atmospheric Administration Status and Trends Program; EPA Environmental Monitoring and Assessment Program) use a 20 percent effects level (i.e. 80% nonaffected) as a threshold of ecological significance (Long, 2000).

2.2. BENTHIC ORGANISMS AND THEIR ENVIRONMENT

For benthic organisms, the nature of their interaction with the sediment is determined by the manner in which food is obtained (trophic type), where their activities are carried on (life position) and their mobility (Fisher, 1982). Feeding types for benthos that are applicable to fresh water are presented in Fisher (1982; after Walker and Bambach, 1974). Feeding types applicable to marine waters are presented in Lee and Swartz (1980). The majority of suspension feeders are located near the sediment-water interface, while suspension-feeding bivalves with siphon tubes, and deposit feeders may burrow deeper. Examples of deep-burrowing species are presented in Table 3.

Among environmental determinants of the type of organisms, and, hence, benthic community structure of an area, sediment grain size is very important because it reflects the hydrodynamic regime and the quantity and quality of organic carbon. High proportions of fines are representative of depositional environments and provide a greater surface area (compared to coarse-grained sediments) for sorption of organic carbon and contaminants.

The microbial degradation of labile organic matter largely determines the redox potential (Eh) and pH observed at various depths in the sediment and is responsible for a variety of secondary reactions involving metals (e.g., desorption, release to pore water, formation of sulfide and associated fixation of trace metals) (Batley et al., 2005). Because the flux of labile organic matter to the sediment is usually much faster than the diffusive flux of oxygen across the sediment water interface, it is commonly observed that oxygen concentrations in sediments become anaerobic close to the sediment-water interface (Batley et al., 2005). The oxic zone may vary in thickness from a few millimeters in silty sediments to several cm in coarser riverine and estuarine sands and is underlain by a suboxic and an anoxic area. This oxygen gradient, along with other reactions described above, leads to vertical zonation in sediments and pore waters of pH, Eh and various chemical species, including Pb and Mn, and trace metals (Batley et al., 2005).

A number of macroinvertebrates can span both oxic and anoxic layers of sediment. Some that ingest particles at depth and egest them upon the sediment surface—the 'head-down' conveyor-belt species of Rhoads (1974)—are major agents of sediment reworking in many benthic communities. These species, some of which are included in Table 3, dominate late successional stage equilibrium assemblages associated with a deeply oxygenated sediment surface where the redox zone commonly reaches depths of over 10 cm (Rhoads and Germano, 1986). Tubificid oligochaetes can feed in anoxic sediment layers while waving their tails in the water column for the purpose of respiration (McCall and Tevesz, 1982). During feeding, material ingested from several centimeters beneath the sediment surface is deposited at the sediment-water interface, resulting in the rapid burial of components originally deposited at the sediment surface as well as the upward transport of subsurface material (including pollutants) (Krezoski and Robbins, 1985). Many marine bivalves use siphon tubes to inspire overlying water, while physically residing in deeper anoxic sediment (Batley et al., 2005).

The benthic community in marine sediments has great taxonomic diversity, including a number of species that burrow to depths greater than 20 cm (see Table 3; Matisoff, 1995). Freshwater sediments are inhabited by a variety of macrobenthos, principally arthropods (insects and amphipods), annelids (oligochaetes and leeches), and mollusks (bivalves and gastropods) (Fisher, 1982). Along with chironomids, tubificid oligochaete worms are usually the dominant macrofauna in lake profundal regions (McCall and Tevesz, 1982). Populations of a few score to a few thousand worms per square meter occur commonly, with higher populations in organically rich environments (Davis, 1974).

2.3. BENTHIC HABITAT TYPES

Chapman et al. (2005) summarize environmental characteristics of five types of water bodies as follows:

> Lacustrine: low-energy environment; generally depositional; groundwater interaction decreasing away from shore; organic matter decreasing with distance from shore; often fine-grained sediment
>
> Riverine: low- to high-energy environment; depositional or erosional; potential for significant groundwater interaction; significant variability in flow and sediment characteristics within and between rivers.
>
> Estuarine: generally low- or moderate-energy environment; generally depositional; generally fine-grained sediment grading to coarse sediment at ocean boundary.
>
> Estuaries are dynamic, complex, and unique systems that can have strong physical-chemical gradients, particularly of salinity, dissolved oxygen, pH, nutrients, sediment grain size, and organic matter content. Estuarine systems are divided into a number of categories based on salinity (see Boesch, 1977). Estuarine sediments can come from inland and/or the sea, depending on the freshwater sediment load and the estuarine circulation patterns. Due to the dynamic nature of sediments in estuaries with strong flows or currents, the stability of estuarine benthic environments can vary and should be taken into account in any ecological assessment. Sediment total organic carbon, which typically varies with fine sediment particles, provides a good overall index of organic loading and composition. It integrates carbon enrichment from multiple sources, including land-based inputs, detritus, and algal and microbial metabolism.

Coastal Marine: relatively high-energy environment, decreasing with depth and distance from shore; often coarse sediments.

Offshore Marine: generally low-energy environment; generally depositional; generally fine-grained sediment.

Benthic communities in marine environments are typically below the photosynthetic zone, other than along the coastal margins. Consequently, benthic food chains are typically built on organic materials carried into the system; thus, the food chain is primarily allochthonous. Materials such as phytoplankton may be filtered from the water, or deposits may provide organic material for bacterial growth, which can then be harvested by filtering or grazing organisms.

2.3.1. LOTIC VERSUS LENTIC ENVIRONMENTS

Lotic environments (include rivers and streams) may be either depositional or erosional. High-gradient streams and other erosional environments differ significantly from lentic systems in terms of major physical processes, factors that limit primary production, nutrient dynamics, types of primary producers, and the relative importance of autochthonous versus allochthonous energy sources (Chapman et al., 2005). The defining feature of lotic environments is the unidirectional flow of water, responsible for the downstream transport of biotic and abiotic materials, including sediments, and the biota (downstream colonization). The potential for movement of sediments is much greater in lotic than lentic environments. Due to greater energy levels and greater potential for sediment transport, grain size is larger, and organic carbon content is generally lower in lotic erosional environments than in lotic depositional or lentic environments. Unlike depositional habitats, fine-grained sediments in erosional environments are highly mobile. Materials such as nutrients, sediments, and contaminants are transported downstream, deposited in slower moving sections of the river, and then resuspended during periods of high discharge. Because the velocity of water flow decreases downstream, mean particle size will generally decrease, and amounts of organic carbon increase, from headwater reaches to downstream reaches (Chapman et al., 2005).

2.3.2. HYPORHEIC ZONE

The hyporheic zone of rivers and streams is the spatially fluctuating ecotone between the surface water body and the deep groundwater where exchanges of water, nutrients, and organic matter occur in response to variations in discharge and bed topography and porosity (Boulton et al., 1998). The interstitial spaces among sediment particles in the hyporheic zone are occupied by a diverse array of aquatic invertebrates, termed the "hyporheos." The hyporheos includes many types of crustaceans, segmented worms, flatworms, rotifers, water mites, and juvenile stages of aquatic insects (Boulton et al., 1998). The organisms inhabiting the hyporheic zone may be either epigean or hypogean depending upon their affinities for surface or subsurface habitat, respectively. Though many insect larvae and epigean crustaceans colonize the superficial benthos of running waters, epigean species can also penetrate deeper where water circulates freely through the sediments and much organic matter and oxygen are available (Ward et al., 1998). The present paper does not cover fauna that live strictly in groundwater zones that can be located 2 – 3 km from river channels (noted in Stanford and Ward, 1993).

The composition of the hyporheos represents a complex response to interstitial water velocity, sediment composition (particularly the amount of fine sediments), sediment pore size, organic matter content, dissolved oxygen concentration, vertical hydrological exchange, and other environmental parameters as well as biological interactions (Boulton, 2007; Dole-Olivier and Marmonier, 1992; Olsen and Townsend, 2003). The deeper layers of the hyporheic zone can serve as a refuge from environmental perturbations such as flooding and drought, or from predation (Griffith and Perry, 1993; Angradi et al., 2001).

2.4. METHODS

Literature relevant to the biotic zone was obtained by searching on the keyword combinations (1) "sediment" AND "biotic zone" OR "bioturbation zone," (2) "sediment" AND "invertebrates" AND "vertical distribution," and (3) "sediment" AND "invertebrates" AND "vertical distribution" AND "sediment type." We searched the literature from 1985 to present but included a number of key references that were older. Data on organism abundance or biomass with depth in the sediment were extracted from tables or graphs. Data from sites that were acknowledged by the study authors to be impacted by a local pollution source were not included. The data available consist of 234 datasets, each consisting of one or more cores from a particular habitat type (see Table 4) that detail the depth distribution of organisms by abundance or biomass. A publication may contain more than one dataset for a habitat type if sets of cores were taken from different locations (within that habitat type) or at different times. The data were summarized by first computing for each dataset an 80th percentile depth. This was determined as the midpoint of the stratum containing the 80th percentile of the abundance or biomass distribution from the sediment surface to depth. Where data were presented on a volume instead of areal basis and the strata were of unequal thickness (e.g., 0−2, 2−5, 5−10 cm), the values were weighted to account for the fact that thicker strata contain a greater volume of sediment.

Based on the 80th percentile of depth distributions, we developed practical default values for the depth of the biotic zone (i.e., biologically relevant sediment depth) in various habitats for decisions related to ecological assessment or remediation. We calculated and graphed the mean 80th percentile depths (for abundance or biomass) for each habitat type; the maximum 80th

percentile depth for each habitat type was also graphed. Each mean 80th percentile depth was rounded to the next (deeper) 5-cm boundary (i.e. 5, 10, 15, etc.) to determine the biologically relevant sampling depth or biotic zone for the respective habitat type. Where the maximum 80th percentile depth for a habitat type exceeded the mean 80th percentile depth by more than 5 cm, we added 5 cm to the mean and rounded to the next boundary to arrive at the biotic zone for that category.

Habitat types were classified by salinity (within estuarine habitats) and sediment type within seven broad categories: estuarine intertidal, tidal freshwater, estuarine subtidal, lentic, lotic, marine coastal, and marine offshore (see Table 4). The lotic category comprised (1) stream coarse grained/sand, (2) stream coarse grained/sand with fines, and (3) river coarse grained/sand with fines, where "fines" denote grain sizes <2 mm in substantial quantity (approximately 20% or more by weight). Sediment types were taken directly from the respective papers or designated using the classification of Shepard (1954). The "mixed" category refers to muddy sand or sandy mud, where mud = silt + clay.

2.5. RESULTS—BENTHIC BIOTIC ZONE: ABUNDANCE AND BIOMASS

The mean and maximum 80th percentile of benthic abundance depth distributions in various habitats are shown in Figure 3. A number of organisms can burrow significantly deeper than the 80th percentile depth distribution (see Table 3 for examples). Nonetheless, in performing ecological assessments related to sediment contaminants, it is important to identify the zone of greatest organism-substrate interaction, i.e., the biotic zone. We developed practical default values for the depth of the biotic zone in various habitats based on the 80th percentile of depth distributions. First we summarize these distributions.

In terms of benthic abundance depth distribution, the mean 80th percentile in estuarine intertidal, tidal freshwater, most estuarine subtidal, and lentic habitats extends to 5–10 cm (see Figure 3). Exceptions are oligohaline and polyhaline mud, and oligohaline sand, where the mean 80th percentile is less than 5 cm. Overall depth distributions within estuarine habitats tend to be deepest in mixed substrates and in sand (except oligohaline sand). The maximum 80th percentiles in estuarine intertidal sand, oligohaline mixed substrates, and polyhaline sand extend to 15–20 cm. The maximum 80th percentile in lakes (profundal mud) extends to 20–25 cm (see Figure 3).

In most marine coastal and offshore habitats, the mean 80th percentile of abundance depth distributions extends to 5–10 cm. Exceptions are marine coastal sand, and marine offshore mixed substrates, where the mean 80th percentile is less than 5 cm. (Note however that only one data set was available for the latter habitat type.) Overall depth distributions in marine coastal and offshore muds tend to be deeper than in other marine substrates, with the maximum 80th percentile for marine coastal mud extending to 15–20 cm.

The mean and maximum 80th percentile of abundance depth distributions in lotic habitats is deeper than that in the other habitats. The three lotic habitats covered here are stream coarse grained/sand, stream coarse grained/sand with fines, and river coarse grained/sand with fines. The mean 80th percentile for these habitats extends to 25–30, 15–20, and 10–15 cm respectively. The maximum 80th percentiles extend to 35–40 cm, 30 cm, and 15 cm respectively (see Figure 3).

In most habitats where data are available, the 80th percentile of depth distributions based on biomass exceeds respective distributions based on abundance. Oligohaline mixed substrates are an exception to this trend (see Figures 3 and 4). The biomass-based depth distribution for lake profundal muds exceeds that for abundance, but this represents an artifact in that biomass data were only available for the profundal area of a shallow lake in Japan, where the fauna (oligochaetes) burrowed deeper than in other localities.

Based on the 80th percentile of depth distributions, and using the procedure outlined in the Methods section, we developed practical default values for the depth of the biotic zone in various habitats. These values, shown in Table 5, may be used for decisions related to ecological assessment or remediation in aquatic scenarios. The biotic zone, based on benthic abundance, in most estuarine and tidal freshwater environments is 10 or 15 cm. Exceptions are oligohaline and polyhaline mud (5 cm) and oligohaline sand (5 cm). In marine muds (both coastal and offshore), the biotic zone is 15 cm. In other marine substrates it is 10 cm (marine coastal mixed and marine offshore sand) or 5 cm (marine coastal sand). In lentic environments, the biotic zone is 15 cm. The biotic zone tends to be deeper when biomass is taken into account. The biotic zone in lotic systems varies from 15 to 35 cm depending upon water/habitat type. In areas populated by a high density of deep dwelling organisms such as those listed in Table 3, the biotic zone may be somewhat deeper than our recommended values.

2.6. DISCUSSION

Organisms in aerobic, sand or mixed (sand and mud) sediments of estuaries tend to penetrate deeper into the substrate than those in mud habitats (Dauer et al., 1987; Nilsen et al., 1982). Deep-dwelling species that exist in mud habitats either have a direct connection to the surface via a tube or permanent burrow, or are tolerant of high sulfide low oxygen conditions. In the present synthesis, in terms of benthic abundance, the practical default values for the biotic zone in estuarine muds range from 5 cm (oligohaline and polyhaline mud) to 10 cm (mesohaline mud), whereas in estuarine sands and estuarine mixed substrates the values range from 5 cm (oligohaline sand) to 15 cm (polyhaline sand and oligohaline mixed substrate) (see Table 5). For most habitat types, the practical default values for the biotic zone are usually deeper when biomass is taken into account. For example, in mesohaline mud, the biotic zone in terms of biomass (25 cm) is relatively deep compared to the biotic zone in terms of abundance (10 cm) (see Table 5). This is largely due to the presence of bivalves such as *Macoma balthica*.

In our synthesis, the general trend of deeper penetration by the benthos in estuarine sands or mixed substrates versus mud is not evident in coastal and offshore environments. In coastal and offshore environments, factors in addition to sediment type may play an important role in determining faunal depth distributions. As one proceeds seaward into the marine coastal environment, the rate of deposition has a controlling effect on the depth distribution of the benthos, with depth penetration increasing with reduced deposition (Rhoads et al., 1985). Areas of the seafloor where sedimentation rates are << 4 cm y^{-1} and where the frequency of physical resuspension or bedload transport is low, display sedimentary fabrics dominated by relatively large equilibrium species that commonly feed 'head down' at depth within the sediment (Rhoads et al., 1985).

With respect to lotic systems, a number of variables are of great importance in determining the depth of the biotic zone. These include dissolved oxygen, quantity of fines (less than 1-2 mm-size grains), and porosity. The lack of pore space at depth can be a barrier to penetration of the sediment by benthos Where fines are of sufficient quantity, they can reduce pore space and lead to clogging of the interstices, or, colmation (Meidl and Schönborn, 2004; Weigelhofer and Waringer, 2003). This makes the sediment too dense to provide living space or to support necessary water exchange between the channel and the hyporheic zone and between the groundwater and the hyporheic zone (Findlay, 1995). In the current synthesis, the greater depth of penetration of benthos in *stream coarse grained/sand without fines*—versus *with substantial* quantities *of fines*—is probably due in part to greater porosity in the former. A similar pattern of greater depth penetration in porous habitats has been noted by McElravy and Resh (1991) and Maridet et al. (1992). It is interesting to note that the more porous *coarse grained/sand without fines* category in our synthesis is comprised mainly of higher order reaches (see Table 4).

2.7. RECOMMENDATION

Ideally, to determine the depth of the biotic zone at a specific location, it is best to use data derived from sampling that area. The depth of bioturbation and the degree of contact between biota and sediment/pore water is influenced by the life habits of the resident organisms (e.g., degree of motility, creation of temporary versus permanent burrows, whether tubiculous or not), and their local environment. Clarke et al. (2001) noted that in making site-specific bioturbation depth estimates, it is advisable to obtain the opinions of local experts in benthic ecology. Where data/expertise are not available, the recommendations in this paper (see Table 5) can serve as guidelines for determining the depth of the biotic zone. When considering the biotic zone depth in the design of a cap for isolating contaminated sediments from the overlying water column, the thickness of the cap should exceed the depth of the biotic zone by a safety margin (sensu Brannon et al., 1986). In areas populated by a high density of deep-dwelling organisms such as those in Table 3, the biotic zone may be somewhat deeper than the values shown in Table 5.

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Table 3. Examples of Deep-Burrowing and/or Feeding Benthos

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments[a]
Annelids (Polychaetes)			
Clymenella torquata	to 30	Rhoads (1967); Mangum (1964); Mach et al. (2012); Nilsen et al. (1982)	Atlantic and Gulf coasts of North America; introduced to coasts of British Columbia (Canada), Washington (USA) and United Kingdom; muddy sand to sand; IT, ST[a]
Clymenella mucosa	to 15-20	Mangum (1964)	North Carolina to Florida (USA); Gulf of Mexico; Caribbean Sea; prefers fine to medium sands; IT, ST
Macroclymene zonalis (formerly in genus *Clymenella*)	to 25	Dauer et al. (1987); Moretzsohn et al. (2015); Mangum (1964)	Maine to Florida, USA; Gulf of Mexico; medium to fine sand; ST
Axiothella rubrocincta	to 30	Kudenov (1978)	British Columbia, Canada south to Mexico and Gulf of California; IT, ST
Sabaco elongatus (formerly *Asychis elongata*)	to 50	Caffrey (1995); Light (1974); Nichols (1979); Read (2015)	Maine to Florida, USA; Gulf of Mexico; Belize; introduced to San Francisco Bay, California (USA), where can occur in dense patches; mud and sandy mud; IT, ST
Maldane sarsi	to 21-25	Blanchard and Knowlton (2013); WoRMS (2015a)	cosmopolitan; IT, ST
Paraonis fulgens	to 20	D'Andrea et al. (2004); Gaston et al. (1992); WoRMS (2015b)	widely distributed in N Atlantic; marine, estuarine; sand; IT, ST
Heteromastus filiformis	to 20-35	Nilsen et al. (1982); Hines and Comtois (1985); Frey (1970); Cadee (1979)	cosmopolitan; marine, estuarine (polyhaline, mesohaline); mud to muddy sand; IT, ST
Notomastus tenuis	to 26	Johnson (1967); Garcia-Garza et al. (2012)	eastern N Pacific from California through Washington, USA; bays, estuaries; IT, shallow ST
Notomastus latericeus	to 20	Swift (1993); Mayhew (2005)	cosmopolitan; sand or muddy sand; low IT to deep ST
Arenicola marina	to 20-40	Cadee (1976); Luttikhuizen and Dekker (2010); Longbottom (1970); Tyler-Walters (2008)	western N Atlantic (Greenland, Bay of Fundy to Long Island); eastern N Atlantic; estuarine, marine; common in fine sand or muddy sand; predominantly IT
Arenicola cristata	to 30+	Lippson and Lippson (2006); Kaplan (1988)	western N Atlantic from Cape Cod to Florida (USA), Gulf of Mexico, Caribbean Sea; marine, estuarine (polyhaline, mesohaline); IT
Arenicola defodiens	to 40-70	Cadman (1997); Luttikhuizen and Dekker (2010)	eastern N Atlantic: British Isles; western Wadden Sea, North Sea; Skagerrak; high-energy low IT and ST

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Abarenicola pacifica	to 20	Krager and Woodin (1993); Rudy and Rudy (1983); Hobson (1967)	N Pacific: Alaska to N California (USA); Japan; muddy sand of coastal bays; predominantly IT
Abarenicola claparedi vagabunda	to 30	Healy and Wells (1959)	Eastern N Pacific: Washington (USA); loose clean sand; low IT
Amphitrite ornata	to 30	Aller and Yingst (1978); WoRMS (2015c); Lippson and Lippson (2006)	western N Atlantic, including Cobscook Bay and Gulf of Maine; marine, estuarine (polyhaline); IT, ST
Lanice conchilega (sand mason)	to 20+	Van Hoey et al. (2006); Ager (2008); de Kluijver et al. (2000a)	Arctic to Mediterranean, Persian Gulf; Pacific; marine, estuarine (polyhaline); sand or muddy sand; IT,ST
Thoracophelia mucronata (formerly in genus *Euzonus*)	to 20	Kozloff (1993); Dales (1952)	Vancouver Island, BC, Canada to Baja California (Punta Banda region), Mexico; sand beaches experiencing fairly heavy surf; IT
Bhawania heteroseta (formerly in genus *Paleanotus*)	to 20	Dauer et al. (1987); Perkins (1985)	W Atlantic from Virginia, USA to Gulf of Mexico; sandy estuarine and marine; ST
Cirriformia moorei	to 22	Ronan et al. (1981) (as *C. spirabrancha*); Light and Carlton (2007)	California, USA; mudflats of estuaries and bays, often associated with eelgrass beds; low IT, ST
Scoletoma zonata (formerly in genus *Lumbrineris*)	to 22	Johnson (1967); Rudy and Rudy (1983)	Alaska to W Mexico; marine, estuarine; IT, ST
Glycera americana	to 40	Nilsen et al. (1982)	prefers mud mesohaline to polyhaline
Glycera dibranchiata	to 40	Nilsen et al. (1982)	wide range of sediments, mesohaline to polyhaline
Nereis succinea	to 40	Nilsen et al. (1982)	wide range of sediments and salinities
Alitta virens (formerly in genus *Nereis*)	to 40	Andersen and Kristensen (1991); Creaser et al. (1983); Glasby (2015)	western N Atlantic: Gulf of St. Lawrence, Canada to Virginia, USA; Iceland; eastern N Atlantic: Norway, North Sea, France, Ireland; White Sea, Russia; IT, ST
Hediste diversicolor (formerly in genus *Nereis*)	to 15-20	Reise (1981); Budd (2008)	Widespread along eastern N Atlantic including Baltic Sea, North Sea, Mediterranean Sea; euryhaline; IT
Chaetopterus cf. *variopedatus* (formerly *C. pergamentaceus*)	to 15+	Thompson and Schaffner (2000, 2001)	W Atlantic from NE USA to Florida; marine, estuarine; IT, ST
Spiochaetopterus costarum oculatus	to 15+	Woodin (1981); Bhaud (1998); Barnes (1964)	W Atlantic from Massachusetts, USA to Gulf of Mexico; IT, ST

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Mesochaetopterus taylori	to 30	Sendall et al. (1995)	eastern N Pacific from British Columbia, Canada to Mexico; muddy sand and among roots of eel grass; IT
Marenzelleria neglecta	to 35	Zettler et al. (1995) (as *M. viridis*); Sikorski and Bick (2004); Bastrop et al. (1998)	Baltic Sea; North Sea (Elbe estuary); Arctic (Northwest Territories, Canada); western N Atlantic from Chesapeake Bay to Georgia, US; predominantly oligohaline to mesohaline; ST
Marenzelleria viridis (formerly in genus *Scolecolepides*)	to 30	Essink and Kleef (1988); Sikorski and Bick (2004); Blank et al. (2008)	North Sea; Baltic Sea; western N Atlantic from Nova Scotia, Canada to Cape Henlopen, Delaware and Chesapeake Bay, US; predominantly mesohaline to polyhaline; IT, ST
Pseudeurythoe ambigua	to 40	Nilsen et al. (1982)	wide range of sediments, mesohaline to polyhaline
Sigambra tentaculata	to 30	Nilsen et al. (1982)	muddy sands mesohaline to polyhaline
Diopatra cuprea	to 50-60	Mangum et al. (1968)	U.S. Atlantic and Gulf of Mexico coasts; IT; builds sand and mucous tube
Onuphis microcephala	to 45	Frey and Howard (1969)	low IT, shallow ST
Scalibregma inflatum	to 30-60	Ashworth (1901)	cosmopolitan; ST
Annelids (Tubificid oligochaetes)			
Various	to 20	McCall and Tevesz (1982)	mainly freshwater
Various	to 30	Reinharz and O'Connell (1983)	estuarine
Tubificoides spp.	to 25	Hines and Comtois (1985)	estuarine/marine
Phoronids			
Phoronopsis harmeri	to 20	Johnson (1967)	mostly intertidal, in tubes
Phoronis spp.	to 20	Nilsen et al. (1982)	sand polyhaline
Nemertea (ribbon worms)			
Cerebratulus lacteus	to 50	Nilsen et al. (1982); Frey (1970)	prefers mud mesohaline to polyhaline; IT, shallow ST
Bivalves (Unionid, or freshwater mussels)			
Elliptio complanata	to 20	Amyot and Downing (1991); Fisher & Tevesz (1976)	Eastern North America lotic and lentic systems; abundant in shallow (< 3 m) waters; those at depth in sediment are significantly smaller than those that are epibenthic
Unio tumidus	to 20	Schwalb and Pusch (2007); Van Damme (2011a)	Europe (widely distributed); lowland fresh waters

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Unio pictorum	to 20	Schwalb and Pusch (2007); Van Damme (2011b)	Widely distributed throughout Europe and Russia; lowland fresh waters
Unio crassus	to 30-35	Schwalb and Pusch (2007); Schultes (2010)	Europe except Iberian Peninsula and British Isles, to Black Sea region and Iraq; sandy and stony substrate of lowland clean rivers and smaller running waters
Anodonta anatina	to 20	Schwalb and Pusch (2007); Lopes-Lima (2014)	N Europe and Asia, below 65 degrees, to Sicily and Turkey; sandy and gravel substrate of lotic and lentic systems
Bivalves (other)			
Macoma balthica	to 30	Hines and Comtois (1985); Schaffner et al. (1987)	important at mesohaline mud and sandy mud sites; burrowing depth varies with shell size
Macoma mitchelli	to 20	Reinharz and O'Connell (1983)	mesohaline, all sediment types
Macoma nasuta	to 10-20	Ricketts et al. (1985)	Eastern N Pacific; IT
Solecurtus strigilatus	to 27	Dworschak (1987a)	Adriatic Sea; eastern N Atlantic from Portugal to Senegal; IT, ST
Tagelus plebeius	to 40+	Frey (1968); Frey (1970); Lippson and Lippson (2006)	Massachusetts to S Florida (USA); Gulf of Mexico; marine, estuarine (polyhaline, mesohaline); mixed mud-sand; IT, ST
Tagelus divisus	to 30	Frey (1968); Lippson and Lippson (2006)	Massachusetts to S Florida (USA); Gulf of Mexico; Caribbean; marine, estuarine (polyhaline); prefers sand or muddy sand; shallow ST
Tagelus californianus	to 50	Ricketts et al. (1985); Morris et al. (1980)	Eastern N Pacific: Humboldt Bay, CA (USA) to Panama; IT
Zirfaea pilsbryi	to 50	Morris et al. (1980)	Alaska to Baja California, Mexico; bays, estuaries, occasionally open coast; heavy mud, sticky clay, soft shale; low IT, ST
Ensis directus	to 20	Nilsen et al. (1982); Gollasch, et al. (2015)	western N Atlantic: Labrador, Canada to South Carolina, USA; eastern N Atlantic (introduced): Spain to Norway, including UK, and western Baltic; marine, estuarine (polyhaline); prefers fine-medium sand; IT, ST
Ensis ensis	to 54	Keegan and Konnecker (1973) (as *Solen ensis*); Von Cosel (1990); de Kluijver et al. (2000b)	eastern N Atlantic: North Sea and British Isles to Portugal and Mediterranean; sand; IT, ST
Ensis siliqua	to 60	Gaspar et al. (1998); de Kluijver et al. (2000c)	eastern N Atlantic: Norway to the Mediterranean; sand; IT, ST

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Solen rostriformis	to 30	Morris et al. (1980) (as *S. rosaceus*); Light and Carlton (2007)	eastern N Pacific from Morro Bay, California (USA) to Mazatlan, Mexico; protected bays; sandy mud; low IT
Solen sicarius	to 30-35	Morris et al. (1980)	eastern N Pacific from Vancouver Island BC, Canada to Baja California, Mexico; sheltered bays, especially in beds of eelgrass; low IT, shallow ST
Mya arenaria (soft-shelled clam)	to 30-40	Hines and Comtois (1985); Zwarts and Wanink (1989); Kondo (1987)	eastern N Pacific; both sides of Atlantic; burrowing depth varies with shell size; marine, estuarine (polyhaline, mesohaline) soft sediments; IT, ST
Lucinoma borealis	to 20	Dando et al. (1986)	NE Atlantic; Mediterranean Sea; low IT, ST
Nuttallia nuttallii	to 30-40	Morris et al. (1980)	eastern N Pacific from Bodega Bay Harbor, California (USA) to Baja California Sur, Mexico; outer coast and in bays with strong tidal currents; sand or gravel; low IT
Nuttallia obscurata	to 30	Fofonoff et al. (2003)	western N Pacific (native): Russia, Japan, China; eastern N Pacific (introduced): Strait of Georgia (Canada) to Puget Sound, Willapa Bay and Coos Bay, Oregon (USA); prefers estuaries (mesohaline, polyhaline) but also marine; IT, shallow ST
Saxidomus gigantea (butter clam)	to 35	Cowles (2005a); Cheney and Mumford (1986)	eastern N Pacific: Aleutian Islands and SE Bering Sea, Alaska to San Francisco Bay; prefers sandy or gravelly substrate with mixed shell; IT, ST
Tresus nuttallii	to 100	Ricketts et al. (1985)	eastern N Pacific; IT
Tresus capax	to 100	Cowles (2005b)	eastern N Pacific from Kodiak Island, Alaska to central California USA; bays, occasionally open coast; mud; IT, ST
Panopea generosa (geoduck)	to 30-100	Willner (2006); Goodwin and Pease (1989); Gosling (2015)	N Pacific: Alaska to Baja California, Mexico; Japan; very abundant in Puget Sound, Washington and British Columbia; burrowing depth is age-dependent (1-yr to 30 cm depth; 10-yr to 90 cm); sand or sand-mud substrates; ST, IT
Panopea zelandica	to 30-45	Ministry for Primary Industries (2013)	New Zealand: North, South and Stewart Islands; ST
Cyrtopleura costata (angel wing)	to 60+	Schaffner et al. (2001); Gustafson et al. (1991); Lippson and Lippson (2006)	western Atlantic from Massachusetts, USA to Brazil; marine, estuarine (polyhaline, mesohaline); sandy mud; low IT, shallow ST

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Insects (Chironomid larvae)			
Chironomus plumosus	to 15	McCall and Tevesz (1982)	lakes
Insects (mayfly larvae)			
Hexagenia limbata	to 20	Matisoff and Wang (1998)	lakes
Insects (beetle)			
Bledius spp	to 40	Wyatt and Foster (1991)	intertidal salt marshes; around lakes/salt lakes and in river banks
Crustaceans (Thalassinidean shrimp)			
Callianassa subterranea	to 86+	Nickell and Atkinson (1995)	North Sea; ST
Callianassa truncata	to 60-70	Kristensen and Kostka (2005); Ziebis et al. (1996)	Mediterranean Sea; sandy sediments; ST
*Callichirus major**	to 215	Griffis and Suchanek (1991); Heard et al. (2007)	SE USA; Gulf of Mexico; Brazil; open beaches; primarily IT, but also shallow ST
*Callichirus islagrande**	to 50	Felder and Griffis (1994)	N Gulf of Mexico; sandy beaches facing higher salinity (≥ 15 ppt) embayments and the Gulf; IT, shallow ST
*Callichirus kraussi**	to 30+	Griffis and Suchanek (1991)	S Africa; IT, ST
Callichirus laurae (formerly in genus *Glypturus*)	to 150	Whitehead et al. (1988); Griffis and Suchanek (1991)	Red Sea; sand or coral sand, sometimes with seagrass cover; IT, ST
*Neocallichirus grandimana** (formerly *Callianassa branneri*)	to 36	Dworschak and Ott (1993)	W Atlantic from Florida, USA to Brazil; protected back-reef sands; IT, shallow ST
*Neocallichirus rathbunae**	to 150	Griffis and Suchanek (1991); Abed-Navandi (2000)	subtropical and tropical western Atlantic; carbonate sediments; ST, IT
*Neocallichirus jousseaumei**	to 90	Griffis and Suchanek (1991); Dworschak (2011)	widely distributed in Indo-W Pacific; coral rubble covered by fine sand; IT, ST
*Trypaea australiensis**	to 100+	Webb and Eyre (2004)	E and SE Australian estuaries; prefers sand flats; IT, ST
*Neotrypaea californiensis**	to 75	Hornig et al. (1989); Campos et al. (2009)	Alaska, USA to W coast Baja California Sur, Mexico; prefers sand; IT
*Neotrypaea gigas**	to 40	Griffis and Suchanek (1991); Campos et al. (2009)	Vancouver Island, Canada to W coast Baja California Sur, Mexico; prefers muddy sand; IT
Sergio guassutinga (formerly in genus *Neocallichirus*)	to 60	Griffis and Suchanek (1991); Manning and Felder (1995)	Brazil; IT

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
*Sergio trilobata**	to 90	Dobbs and Guckert (1988); Manning and Lemaitre (1993)	Gulf coast of Florida, USA; IT, ST
*Pestarella tyrrhena**	to 62	Dworschak (1987b, 2004)	Adriatic Sea; eastern N Atlantic; IT, shallow subtidal
*Pestarella candida**	to 65	Dworschak (2002)	Adriatic Sea; IT, ST
*Pestarella whitei**	to 28+	Dworschak (2002)	Adriatic Sea; coarse sand or mud under stones; IT, shallow ST
*Lepidophthalmus louisianensis**	to 250	Griffis and Suchanek (1991); Felder and Griffis (1994)	N Gulf of Mexico; muddy shorelines of low salinity (10-15 ppt) estuaries; IT, shallow ST
Lepidophthalmus sinuensis	to 50	Felder and Griffis (1994); Nates & Felder (1999)	estuaries on Caribbean coast of Colombia; IT, ST
*Biffarius filholi**	to 45	Griffis and Suchanek (1991); Berkenbusch and Rowden (2000)	New Zealand; IT and shallow ST
*Biffarius arenosus**	to 58	Bird and Poore (1999)	E and SE Australia; sand and mud flats; IT, ST
Corallianassa longiventris	to 150	Griffis and Suchanek (1991); Dworschak et al. (2006)	W Atlantic from Bermuda to Brazil; back-reef sediments near seagrass beds; ST
*Corallianassa coutierei**	to 69	Kneer et al (2008); Sepahvand et al. (2013)	Indo-W Pacific; carbonate sand and coral rubble; IT, ST
*Nihonotrypaea japonica**	to 65	Tamaki and Ueno (1998); Tamaki et al. (1999)	Japan; polyhaline, extensive sandflats of medium-fine sands; IT
*Nihonotrypaea harmandi**	to 36+	Tamaki and Ueno (1998); Tamaki et al. (1999)	Japan; euhaline, small to medium sandflats and beaches of medium-fine sands; IT
Glypturus acanthochirus	to 160	Griffis and Suchanek (1991); Dworschak and Ott (1993)	Florida, Virgin Islands, Belize; bare sediments of mangrove channels and back-reef subtidal sediments; IT, ST
Glypturus armatus	to 150	Griffis and Suchanek (1991)	S Pacific; Aldabra; Seychelles; sheltered reef sediments; IT, ST
Calocaris macandreae	to 22	Nash et al. (1984)	North Sea; ST
Neaxius acanthus	to 50	Kneer et al. (2008)	Indo-W Pacific; carbonate sand and coral rubble with seagrass cover; ST
Upogebia affinis	to 50	Heard et al. (2007)	Massachusetts to S Texas, USA; firm mud or mud-sand substrates; IT, ST
Upogebia deltaura	to 65	Tunberg (1986); Christiansen (2000)	eastern N Atlantic; North Sea; ST
Upogebia pugettensis	to 90	Griffis and Suchanek (1991); Campos et al. (2009)	Alaska to Morro Bay California, USA; IT
Upogebia stellata	to 26.5	Nickell and Atkinson (1995)	North Sea; ST

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Upogebia pusilla	to 80	Dworschak (1987b, 2004)	Mediterranean Sea; eastern N Atlantic; IT, ST
Upogebia africana	to 60	Griffis and Suchanek (1991)	S Africa; IT, ST
Upogebia tipica	to 40	Griffis and Suchanek (1991)	Adriatic Sea; ST
Upogebia macginitieorum	to 60	Griffis and Suchanek (1991); Campos et al., (2009)	S California, USA to Baja California Sur, Mexico
Upogebia major	to 208	Kinoshita (2002)	Japan; IT
Jaxea nocturna	to 92	Nickell and Atkinson (1995); Pervesler and Dworschak (1985)	North Sea; Adriatic Sea; ST
Axiopsis serratifrons	to 100	Griffis and Suchanek (1991); Kensley (1980)	Circumtropical; back-reef areas; ST
Axianassa australis	to 130	Dworschak and Rodrigues (1997); Felder et al. (2009)	western Atlantic from Florida USA to Brazil, including Gulf of Mexico and Colombia; muddy sand or mud near mangroves; IT
Crustaceans (snapping shrimp)			
Alpheus heterochaelis	to 100	Howard and Frey (1975); McClure (1995)	widespread throughout temperate and tropical W Atlantic; bays and quiet waters; IT, shallow ST
Alpheus floridanus (a species complex)	to 36	Dworschak and Ott (1993); Soledatde and Almeida (2013)	W Atlantic: S Florida USA, Bahamas, Mexico, West Indies, Brazil; IT, ST
Crustaceans (mantis shrimp)			
Squilla empusa	to 15-50	Myers (1979); Mead and Minshall (2012); Lippson and Lippson (2006)	winter burrows up to 410 cm depth; western N Atlantic from Cape Cod to Gulf of Mexico; silty substrates; low IT, ST
Squilla mantis	to 31	Atkinson and Froglia (1999); Ragonese et al. (2012)	Mediterranean Sea and eastern Atlantic from Gulf of Cadiz to Angola; soft substrates; ST
Lysiosquilla scabricauda	to 150	Bieler and Mikkelsen (1988); Foster et al. (2004)	W Atlantic, from South Carolina USA to S Brazil, including Gulf of Mexico, Caribbean, Bahamas, Bermuda; IT, ST
Crustaceans (ghost crabs)			
Ocypode quadrata	to 100+	Pombo and Turra (2013); Knott (2010)	W Atlantic from Rhode Island USA to Brazil, including Gulf of Mexico and Caribbean; upper intertidal to fore dunes of sandy beaches

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Crustaceans (fiddler crabs)			
Uca pugilator (Atlantic sand fiddler)	to 34	Christy (1982)	Massachusetts to Texas, USA; sandy upper intertidal and supratidal substrates in tidal marshes, bays and sounds
Uca pugnax (Atlantic marsh fiddler)	to 15-25	Montague (1980); Bergey and Weis (2008)	Massachusetts to Florida, USA; muddy intertidal substrates in salt marshes in sheltered bays and estuaries
Uca minax (red-jointed fiddler)	to 30-65	Montague (1980); Powers (1977)	Massachusetts to NE Florida, USA; Gulf of Mexico; freshwater or brackish water tidal marshes, often supratidal
Crustaceans (other crabs)			
Helice tridens	to 40	Takeda and Kurihara (1987)	Japan; salt marsh
Neohelice granulata (formerly in genus *Chasmagnathus*)	to 33	Iribarne et al. (1997)	SW Atlantic; mud flats and marshes (deepest burrows in vegetated marshes)
Sesarma reticulatum (marsh crab)	to 30+	Koretsky et al. (2002); Abele (1992)	eastern North America and Gulf of Mexico salt and brackish marshes; IT
Eurytium limosum	to 30	Koretsky et al. (2002); Felder et al. (2009)	W Atlantic from New York, USA to Brazil; Gulf of Mexico; Caribbean Sea; vegetated and unvegetated salt marshes; IT
Crustaceans (lobsters)			
Nephrops norvegicus (Norway Lobster)	to 25	Rice and Chapman (1971)	
Homarus americanus (American lobster)	to 60-80	Cooper and Uzmann (1980)	western N Atlantic from Labrador, Canada to North Carolina, USA; ST
Crustaceans (crayfish)			
Cambarus diogenes (devil crawfish)	to 457	Hobbs and Hart (1959); Hobbs (1989); Cordeiro et al. (2010)	widespread east of the Rockies and south of Great Lakes, except peninsular Florida and the Alleghenies (USA); Ontario, Canada; ponds and streams in spring season; burrows in banks of streams
Procambarus clarkii (red swamp crayfish)	to 70	Oluoch (1990); Hobbs (1989); FAO (2007)	N Mexico to Escambia County Florida, and north to S Illinois and Ohio; widely introduced elsewhere; sluggish waters of lentic and lotic habitats
Crustaceans (amphipods)			
Pseudohaustorius caroliniensis	to 20-30	D'Andrea et al. (2004)	IT

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Echinoderms (Holothurians or sea cucumbers)			
Pseudocucumis mixta	to 15-25	Konnecker and Keegan (1973)	W coast Ireland
Holothuria arenicola	to 15-20	Mosher (1980)	circumtropical
Molpadia oolitica	to 20	Rhoads and Young (1971); Pawson et al. (2010)	western N Atlantic from Massachusetts to Florida (USA); Gulf of Mexico; mud; ST
Molpadia intermedia	to 35	Lambert (1997)	eastern N Pacific from Kodiak Island, Alaska to Gulf of Panama; mud; ST
Echinoderms (heart urchins)			
Echinocardium cordatum	to 15-20	Rees and Dare (1993); Kroh (2015)	cosmopolitan; typically sand or muddy sand; mainly ST
Cnidarians (anthozoans)			
Ceriantheopsis americanus	to 60+	Nilsen et al. (1982); Frey (1970)	IT, shallow ST
Pachycerianthus fimbriatus	to 100	Light and Carlton (2007); Cowles (2010)	S Alaska to Baja California, Mexico; predominantly in very soft mud; ST, rarely IT
Sipunculids (peanut worms)			
Golfingia elongata	to 40	Keegan (1974); Cutler (1994); de Kluijver et al. (2000d)	widespread: western and eastern N Atlantic, including Mediterranean; Pacific (East and South China Seas); muddy sand or gravel; low IT, ST
Golfingia vulgaris	to 30-50	Swift (1993); de Kluijver et al. (2000e)	widespread but patchy distribution: N Atlantic from Greenland and northern Norway to W Africa and eastern Mediterranean; Indo-West Pacific region; Antarctic; muddy sand or gravel; low IT to several hundred meters
Sipunculus nudus (a species complex)	to 15-35	Volkel and Grieshaber (1992); Kawauchi and Giribet (2014); de Kluijver et al. (2000f)	cosmopolitan; low IT, ST
Echiuran worms			
Maxmuelleria lankesteri	to 80	Hughes et al. (1996)	widespread around British and Irish coasts, most commonly in fine muds
Urechis caupo (fat innkeeper worm)	to 36+	Julian et al. (2001); Arp et al. (1992)	California, USA; mudflats; IT, ST
Echiurus echiurus	to 50	Anker et al. (2005); Pilger and Murina (2015); Ricketts et al. (1985)	widely distributed in the arctic, both in northern part of N. Atlantic and in N. Pacific, as far south as 45° N Latitude; IT, ST

Table 3. Examples of Deep-Burrowing and/or Feeding Benthos (continued)

Faunal Group/Species	Sediment Depth (cm)	Reference	Comments
Enteropneusts (acorn worms)			
Balanoglossus gigas	to 30	Bjornberg (1959); van der Land (2015)	W Atlantic from Georgia, USA to SE Brazil, Gulf of Mexico; Greater Antilles; IT
Balanoglossus aurantiaca (= *B. aurantiacus*)	to 60	Duncan (1987); Frey 1970); Konikoff et al. (2015)	W North Atlantic; IT, shallow ST
Balanoglossus clavigerus	to 60	Bromley (1996)	Mediterranean Sea; British Isles; IT
Balanoglossus australiensis	to 20-25	Morton (1950); Konikoff and van der Land (2015)	Gulf of Carpentaria; New Zealand; New South Wales, Australia; Solomon Sea, Great Barrier Reef; fine sand; IT, ST
Saccoglossus kowalevskii	to 25-40	Carey and Farrington (1989); Smith et al. (2003)	Georgia to Maine, USA; IT, shallow ST
Saccoglossus horsti	to 10-20	Burden-Jones (1951)	The Solent, UK; IT
Saccoglossus ruber (synonymised with *S. cambrensis*)	to 5-25	Knight-Jones (1953); Burdon-Jones and Patil (1960)	Welsh coast; W coast Ireland; IT

[a]Intertidal and subtidal represented by IT and ST, respectively.

[*]formerly in genus *Callianasssa*

Table 4. Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions. Abundance and biomass data denoted by A and B, respectively. *N* = number of datasets. (The total number of cores comprising datasets from each habitat type/reference pair is noted in parentheses.)

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
Estuarine Intertidal					
Intertidal Mixed	Mermillod-Blondin et al. (2003) (A)	1(3)	St. Lawrence Estuary, Canada	Cylindrical tube; 78.5 cm^2 by 20 cm; 0.5 mm	Temperate N. Atlantic/Gulf of St. Lawrence-Eastern Scotian Shelf
Intertidal Sand	Johnson (1967) (A)	4(32)	White Gulch and Lawsons Flat, Tomales Bay, California, USA	Brass coring tube; 25 cm^2 by 25 cm; core dissected	Temperate N. Pacific/ Northern California
	Rodil et al. (2008) (A)	18(54)	Sheltered beach on inner part of Ria of Arousa on NW coast of Iberian Peninsula, Spain	Metal core; 188.7 cm^2 by 25 cm; 1 mm	Temperate N. Atlantic/ South European Atlantic Shelf
	D'Andrea et al. (2004) (A)	4(12)	Debidue Flat, South Carolina, USA	Core; 38.5 cm^2 by 30 cm; 0.5 mm	Temperate N. Atlantic/ Carolinean
Intertidal Poikilohaline Mixed	Mucha et al. (2004) (A)	1(3)	Douro Estuary, Portugal	Core sampler; 35 cm^2 by 15 cm; 0.5 mm	Temperate N. Atlantic/ South European Atlantic Shelf
Intertidal Poikilohaline Sand	Mucha et al. (2004) (A)	4(12)	Douro Estuary, Portugal	Core sampler; 35 cm^2 by 15 cm; 0.5 mm	Temperate N. Atlantic/ South European Atlantic Shelf
Tidal Freshwater					
Tidal Freshwater Mixed	Dauer et al. (1987) (A,B)	1(3)	Lower Chesapeake Bay tributaries (James, York and Rappahanock rivers), USA	Box corer; 184 cm^2 by 25 cm; 0.5 mm	Temperate N. Atlantic/ Virginian
	Schaffner et al. (1987) (A,B)	3(3)	James River Estuary (Chesapeake Bay Tributary), USA	Spade box corer; 600 cm^2 by 50 cm; 0.5 mm	Temperate N. Atlantic/ Virginian

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
Estuarine Subtidal					
Oligohaline Mixed	Schaffner et al. (1987) (A,B)	2(2)	James River Estuary (Chesapeake Bay Tributary), USA	Spade box corer; 600 cm^2 by 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Reinharz and O'Connell (1983) (A,B)	2(4)	Upper Chesapeake Bay	Spade box corer; 630 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Oligohaline Mud	Schaffner et al. (1987) (A,B)	1(1)	James River Estuary (Chesapeake Bay Tributary), USA	Spade box corer; 600 cm^2 by 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Reinharz and O'Connell (1983) (A,B)	1(3)	Upper Chesapeake Bay	Spade box corer; 630 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Oligohaline Sand	Reinharz and O'Connell (1983) (A,B)	2(3)	Upper Chesapeake Bay	Spade box corer; 630 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Mesohaline Mixed	Schaffner et al. (1987) (A,B)	2(2)	James River Estuary (Chesapeake Bay Tributary), USA	Spade box corer; 600 cm^2 by 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Reinharz and O'Connell (1983) (A,B)	2(8)	Central Chesapeake Bay	Spade box corer; 630 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Mesohaline Mud	Dauer et al. (1987) (A,B)	2(6)	Lower Chesapeake Bay tributaries (James, York and Rappahanock rivers), USA	Box corer; 184 cm^2 by 25 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Hines and Comtois (1985) (A,B)	1(10)	Mouth of Rhode River, Chesapeake Bay, USA	Scuba-collected cores; 80 cm^2 by 35 cm within 900 m^2 area; 0.5 mm	Temperate N. Atlantic/Virginian

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
	Schaffner et al. (1987) (A,B)	3(3)	James River Estuary (Chesapeake Bay Tributary), USA	Spade box corer; 600 cm^2 by 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Reinharz and O'Connell (1983) (A,B)	2(20)	Central Chesapeake Bay	Spade box corer; 630 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Mesohaline Sand	Hines and Comtois (1985) (A,B)	1(10)	Mouth of Rhode River, Chesapeake Bay, USA	Scuba-collected cores: 80 cm^2 by 35 cm within 900 m^2 area; 0.5 mm	Temperate N. Atlantic/Virginian
	Reinharz and O'Connell (1983) (A,B)	1(2)	Central Chesapeake Bay	Spade box corer; 630 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Polyhaline Mixed	Dauer et al. (1987) (A,B)	2(5)	Lower Chesapeake Bay tributaries and mainstem, USA	Box corer; 184 cm^2 by 25 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Nilsen et al. (1982)[a] (A)	6(6)	Lower Chesapeake Bay, USA	Spade box corer; 620 cm^2 by up to 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Polyhaline Mud	Dauer et al. (1987) (A,B)	1(2)	Lower Chesapeake Bay Mainstem, USA	Box corer; 184 cm^2 by 25 cm; 0.5 mm	Temperate N. Atlantic/Virginian
	Nilsen et al. (1982)[b] (A)	3(3)	Lower Chesapeake Bay, USA	Spade box corer; 620 cm^2 by up to 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Polyhaline Sand	Nilsen et al. (1982)[a] (A)	6(6)	Lower Chesapeake Bay, USA	Spade box corer; 620 cm^2 by up to 50 cm; 0.5 mm	Temperate N. Atlantic/Virginian
Lentic					
Lake Profundal Mud	Fukuhara et al. (1987) (A,B)	4 (8)	Profundal region of shallow lake (Suwa), Central Japan; tubificid oligochaetes (*Limnodrilus*)	Lenz grab; 225 cm^2 by 33 cm; 0.2 mm	Palearctic/Biwa Ko[c]

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
	Newrkia and Wijegoonawardana (1987) (A)	2 (14)	prealpine lake (Mondsee), Upper Austria; oligochaetes	Modified Kajak corer; 19.6 cm^2 by 20 cm; 0.2 mm	Palearctic/Upper Danube
	Cole (1953) (A)	2(90)	Douglas Lake, Michigan, USA; tubificid oligochaetes (*Limnodrilus*)	Small vertical core sampler; 3.8 cm^2 by 24 cm; 0.18 mm (upper 10 cm) – 0.21 mm (below 10 cm)	Nearctic/ Laurentian Great Lakes
	Milbrink (1973) (A)	4(15)	Lake Malaren and Lake Erken, Sweden; tubificid oligochaetes	Microstratification sampler; 167 cm^2 by up to 19 cm; 0.3 mm	Palearctic/N. Baltic Drainages
	Boyer and Whitlatch (1989) (A)	1(16)	Caribou Island Basin of Lake Superior; oligochaetes	Modified 225 cm^2 Eckman box corer; subcores 13.7 cm^2 by up to 16 cm; 0.3 mm	Nearctic/ Laurentian Great Lakes
	Sarkka and Paasivirta (1972) (A)	1(35)	Lake Paijanne, Finland; tubificid and lumbriculid oligochaetes	Lenz sampler; 260 cm^2 by 30 cm; 0.8 mm	Palearctic/N. Baltic Drainages
Lotic					
Stream Coarse Grained/Sand	James et al. (2008) (A)	6(24)	Three small streams, southern North Island, New Zealand	Hyporheic colonization chambers; 78.5 cm^2 by 40 cm; 0.5 mm	Australasia/New Zealand
	Omesová and Helešic (2007) (A)	1(10)	Loucka River, 4th-order stream, Czech Republic	Liquid nitrogen freeze cores; 19.6 cm^2 by 20 cm; 0.1 mm	Palearctic/Upper Danube
	Olsen and Townsend (2005) (A)	1(14)	Kye Burn, 4th-order stream, South Island, New Zealand	Liquid nitrogen freeze cores; 9.6 cm^2 by 50 cm; 0.25 mm	Australasia/New Zealand
	Olsen et al. (2001) (A)	3(18)	Kye Burn, South Island, New Zealand	Liquid nitrogen freeze cores; 9.6 cm^2 by 50 cm; 0.25 mm	Australasia/New Zealand

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
	Maridet et al. (1992) (A)	3(4)	Loire River (5th-order reach), Galaure (3rd-order reach) and Drac (alpine torrential stream, 3rd-order reach), France	Liquid nitrogen freeze cores with in situ electro-positioning; 19.6 cm^2 by 60 cm; macroinvertebrates separated by elutriation	Palearctic/Central and Western Europe
	Angradi et al. (2001) (A)	3(90)	2nd, 3rd and 4th-order reaches of Elklick Run at Fernow Experimental Forest, West Virginia, USA	Multilevel colonization samplers; 95 cm^2 by 30 cm; 0.25 mm	Nearctic/Teays-Old Ohio
Stream Coarse Grained/Sand with Fines	Angradi et al. (2001) (A)	1(30)	1st-order reach of Elklick Run at Fernow Experimental Forest, West Virginia, USA	Multilevel colonization samplers; 95 cm^2 by 30 cm; 0.25 mm	Nearctic/Teays-Old Ohio
	Strommer and Smock (1989) (A)	1(415)	1st-order stream in Blackwater River watershed, Virginia, USA	Cores frozen on dry ice; 18.1 cm^2 by up to 40 cm; 0.053 mm	Nearctic/ Appalachian Piedmont
	Winkelmann et al. (2003) (A)	2(12)	Two small 2nd-order mountain streams, Gauernitzbach and Tannichtgrundbach, that drain into the River Elbe, Germany	Liquid nitrogen freeze cores; 19.6 cm^2 by 30 cm; macroinvertebrates separated by hand-picking and elutriation	Palearctic/ Central and Western Europe
	Adkins and Winterbourn (1999) (A)	2(40)	Two upland streams, Middle Bush and Grasmere, South Island, New Zealand	Dry ice freeze cores; 9.6 cm^2 by 30 cm; 0.12 mm	Australasia/New Zealand
	Meidl and Schönborn (2004) (A)	4(20)	Schwarza Brook, low mountain stream in Thuringian Slate Mountains, Germany	Liquid nitrogen freeze cores with in situ electro-positioning; 19.6 cm^2 by 60 cm; macroinvertebrates separated by sorting	Palearctic/ Central and Western Europe

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80^{th} Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
	Varricchione et al. (2005) (A)	4(54)	Glaciated stream sites (Montana; 2 data sets), and unglaciated stream sites (Idaho; 2 data sets), USA	Liquid nitrogen freeze cores with in-situ electro-positioning; 19.6 cm^2 by 50 cm; 0.063 mm	Glaciated: Nearctic/ Columbia Glaciated; Upper Missouri Unglaciated: Nearctic/ Columbia Unglaciated; Upper Snake; Bonneville
	McElravy and Resh (1991) (A)	5(40)	2^{nd}-order reach of Big Canyon Creek, northern California Coast Range, USA	Substrate colonization samplers; 44.2 cm^2 by 35 cm; 0.063 mm	Nearctic/Sacramento-San Joaquin
	Maridet et al. (1996) (A)	3(35)	Three streams (Vianon, Ozange, Triouzoune) in French granitic Massif Central mountains, France	Liquid nitrogen freeze cores with in situ electro-positioning; 19.6 cm^2 by 60 cm; 0.5 mm	Palearctic/Cantabric Coast-Languedoc
	Weigelhofer and Waringer (2003) (A)	2(66)	3^{rd}-order reach of the Weidlingbach, a tributary of the Danube, northwest of Vienna, Austria	Liquid nitrogen freeze cores with in situ electro-positioning; 19.6 cm^2 by 60 cm; 0.1 mm	Palearctic/Upper Danube
	Marchant (1988) (A)	1(17)	Thomson River, 10 km downstream of Thomson Dam, Victoria, Australia	Dry ice freeze cores; 9.6 cm^2 by 30 cm; 0.15 mm	Australasia/Bass Strait Drainages
	Poole and Stewart (1976) (A)	5(10)	Brazos River, Texas, USA	Vertical stratification colonization sampler; 201.1 cm^2 by 40 cm; 0.5 mm	Nearctic/East Texas Gulf
	Marchant (1995) (A)	6(30)	Acheron River, Victoria, Australia	Dry ice freeze cores; 9.6 cm^2 by 30 cm; invertebrates separated by floatation	Australasia/ Murray-Darling
Marine Coastal					
Marine Coastal Mixed	Dauwe et al. (1998) (A,B)	2(7)	Frisian Front and German Bight, North Sea	Cylindrical Reineck type box corer; 754.8 cm^2 by up to 50 cm; 0.5 mm	Temperate N. Atlantic/ North Sea
	Rhoads et al. (1985) (A,B)	1(?)[d]	East China Sea off Changjiang	0.25 m^2 spade box corer; 181.5 cm^2 by up to 43 cm; 0.5 mm	Temperate N. Pacific/ East China Sea

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
Marine Coastal Mud	Simonini et al. (2004) (A,B)	2(48)	Off of Po and Adige-Brenta river deltas, North Adriatic Sea	Box corer; 200 cm^2 by 20 cm; 0.5 mm	Temperate N. Atlantic/ Adriatic Sea
	Hayashi (1988) (A,B)	1(5)	Sado Strait, Sea of Japan	0.1 m^2 box corer; 225 cm^2 by 25 cm (2 or 3 per box core); 0.5 mm	Temperate N. Pacific/ Sea of Japan
	Moodley et al. (1998) (A,B)	6(12)	Adriatic Sea, northern basin	Large box corer; 283.5 cm^2 by 20 cm perspex cores (2 per box core); 0.5 mm	Temperate N. Atlantic/ Adriatic Sea
	Moodley et al. (2000) (A,B)	2(4)	Adriatic Sea, northern and middle basins	Large box corer; 283.5 cm^2 by 20 cm perspex cores (2 per box core); 0.5 mm	Temperate N. Atlantic/ Adriatic Sea
	Rhoads et al. (1985) (A,B)	2(?)[d]	East China Sea off Changjiang	0.25 m^2 spade box corer; 181.5 cm^2 by up to 43 cm; 0.5 mm	Temperate N. Pacific/ East China Sea
Marine Coastal Sand	Dauwe et al. (1998) (A,B)	1(3)	Broad Fourteens, North Sea	Cylindrical Reineck type box corer; 754.8 cm^2 by up to 50 cm; 0.5 mm	Temperate N. Atlantic/ North Sea
	Spies and Davis (1979) (A)	1(5)	Santa Barbara Channel, California, USA	Tin core samplers; 73.9 cm^2 by up to 35 cm; 0.5 mm	Temperate N. Pacific/ S. California Bight
	Oliver et al. (1980) (A)	1(10)	Monterey Bay, California, USA	Diver-operated corer; 180 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Pacific/ N. California
	Oliver et al. (1980) (B)	1(4)	Monterey Bay, California, USA	Hydraulic suction dredge; 0.25 m^2 cylinder; 1.0 mm mesh bags	Temperate N. Pacific/ N. California
Marine Offshore					
Marine Offshore Mixed	Rhoads et al. (1985) (A,B)	1(?)[d]	East China Sea off Changjiang	0.25 m^2 spade box corer; 181.5 cm^2 by up to 43 cm; 0.5 mm	Temperate N. Pacific/ East China Sea
Marine Offshore Mud	Stull et al. (1996) (A,B)	1(3)	Palos Verdes Shelf, California, USA	Gray-O'Hara box corer; 500 cm^2 by up to 50 cm; 1.0 mm	Temperate N. Pacific/ S. California Bight

Table 4. **Data Sources and Information (Realms/Ecoregions after Spalding et al., 2007 [marine] and Abell et al., 2008 [freshwater]) used to Determine 80th Percentile of Benthic Abundance (see Figure 3) and Benthic Biomass (see Figure 4) Depth Distributions (continued).**

Habitat Type	Reference	*N* (Total Cores)	Location	Sampler; Sample Area and Depth; Sieve Size	Realm/ Ecoregion(s)
	Dauwe et al. (1998) (A,B)	1(2)	Skagerrak, North Sea	Cylindrical Reineck type box corer; 754.8 cm^2 by up to 50 cm; 0.5 mm	Temperate N. Atlantic/ North Sea
	Rhoads et al. (1985) (A,B)	1(?)[d]	East China Sea off Changjiang	0.25 m^2 spade box corer; 181.5 cm^2 by up to 43 cm; 0.5 mm	Temperate N. Pacific/ East China Sea
	Hayashi (1988) (A,B)	2(10)	Sado Strait, Sea of Japan	0.1 m^2 box corer; 225 cm^2 by 25 cm (2 or 3 per box core); 0.5 mm	Temperate N. Pacific/Sea of Japan
	Moodley et al. (2000) (A,B)	1(2)	Adriatic Sea, northern and middle basins	Large box corer; 283.5 cm^2 by 20 cm perspex cores (2 per box core); 0.5 mm	Temperate N. Atlantic/Adriatic Sea
	Josefson (1981) (A)	2(30)	Skagerrak, North Sea	0.1 m^2 box corer; 500 cm^2 by 28 cm (1 per box core); 1.0 mm	Temperate N. Atlantic/ North Sea
Marine Offshore Sand	Simonini et al. (2004) (A,B)	1(24)	North Adriatic Sea, offshore	Box corer; 200 cm^2 by 20 cm; 0.5 mm	Temperate N. Atlantic/ Adriatic Sea
	Oliver et al. (1980) (A)	2(14)	Monterey Bay, California, USA	Diver-operated corer; 180 cm^2 by up to 60 cm; 0.5 mm	Temperate N. Pacific/ N. California
	Oliver et al. (1980) (B)	1(4)	Monterey Bay, California, USA	Hydraulic suction dredge; 0.25 m^2 cylinder; 1.0 mm mesh bags	Temperate N. Pacific/ N. California

[a]Includes data sets from meso-polyhaline (2) and poly-euhaline (2) transition zones.
[b]Includes two data sets from meso-polyhaline transition zone.
[c]The ecoregion Biwa Ko is described as one consisting of *large lakes* habitat. Lake Suwa, the location for our data, is a *small* lake near Lake Biwa Ko.
[d]Number of subcores representing a box core is not specified.

Table 5. Biologically Relevant Sediment Depths—Biotic Zones—for Decisions Related to Ecological Assessment or Remediation. The biotic zone noted in column 2 is based on benthic abundance. The biotic zone shown in column 3 is based on benthic biomass (where information was available). Note that the biotic zone tends to be deeper when biomass is taken into account.

Habitat Type	Biotic Zone (cm)	Biotic zone (cm) (Considering Biomass)
Estuarine Intertidal		
Estuarine Intertidal Sand	15	
Estuarine Intertidal (Other Substrates)	*	
Estuarine Intertidal Poikilohaline	10	
Tidal Freshwater		
Tidal Freshwater Mixed Substrate	10	15
Estuarine Subtidal		
Oligohaline Sand	5	10
Mesohaline Sand	10	20
Polyhaline Sand	15	
Oligohaline Mud	5	5
Mesohaline Mud	10	25
Polyhaline Mud	5	*
Oligohaline Mixed Substrate	15	15
Mesohaline Mixed Substrate	10	30
Polyhaline Mixed Substrate	10	15
Lentic		
Lake Profundal Mud[a]	15	20
Lotic		
Stream Coarse Grained/Sand	35	
Stream Coarse Grained/Sand with Fines[b]	25	
River Coarse Grained/Sand with Fines[b]	15	
Marine Coastal		
Sand	5	20
Mud	15	15
Mixed Substrate	10	15
Marine Offshore		
Sand	10	20
Mud	15	20
Mixed Substrate	*	*

*Biotic zone not estimated because based on only one data set.
[a]Biotic zones for this category are based on oligochaetes.
[b]Fines denote grain sizes <2 mm in substantial quantity (approximately 20% or more by weight).

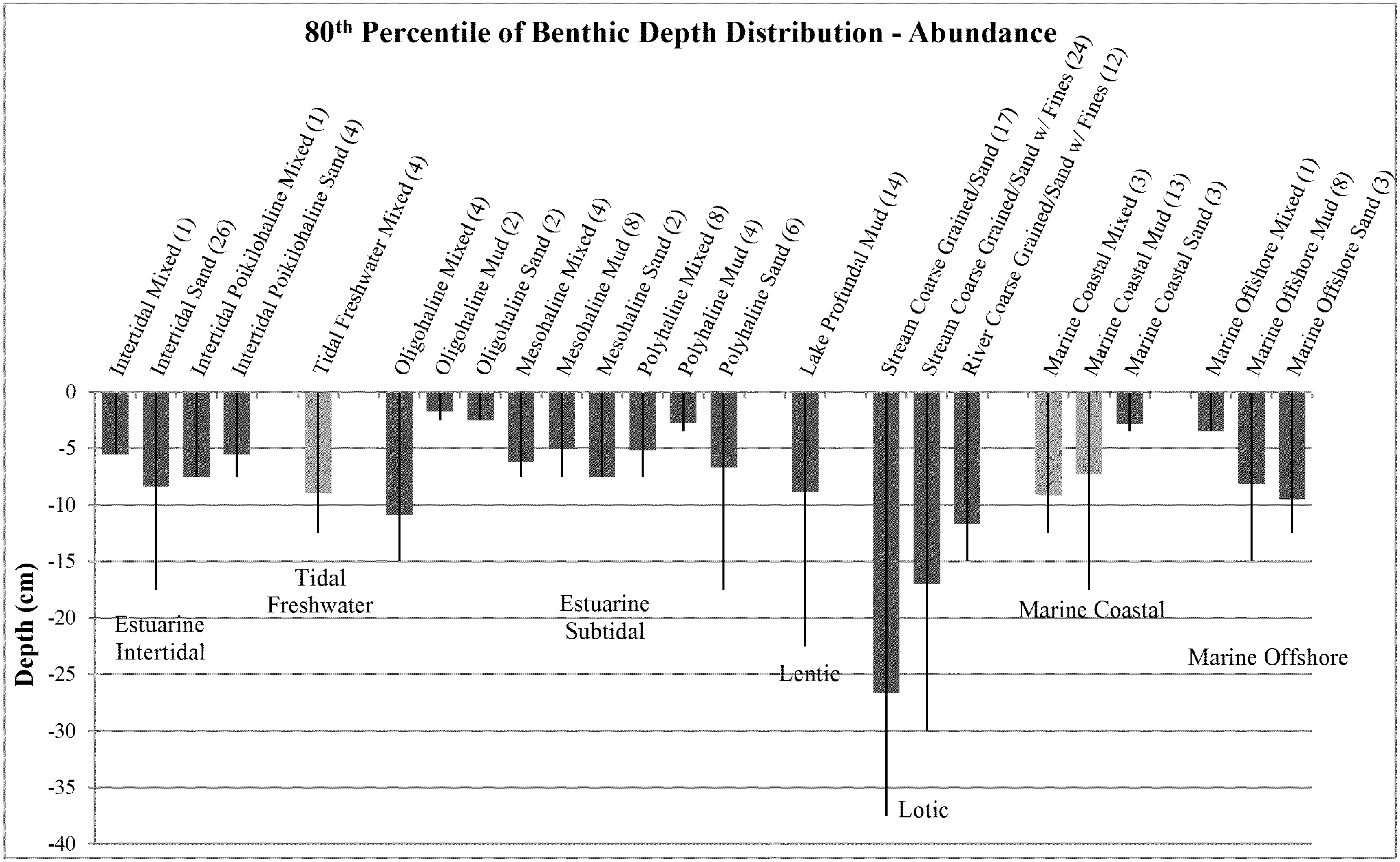

Figure 3. Mean 80th Percentile of Benthic Abundance Depth Distribution (+ Maximum 80th Percentile) in Various Habitats. Number of data sets in parentheses (the number of cores comprising data sets from each habitat type is noted in Table 4). Also see Table 4 for data locations.

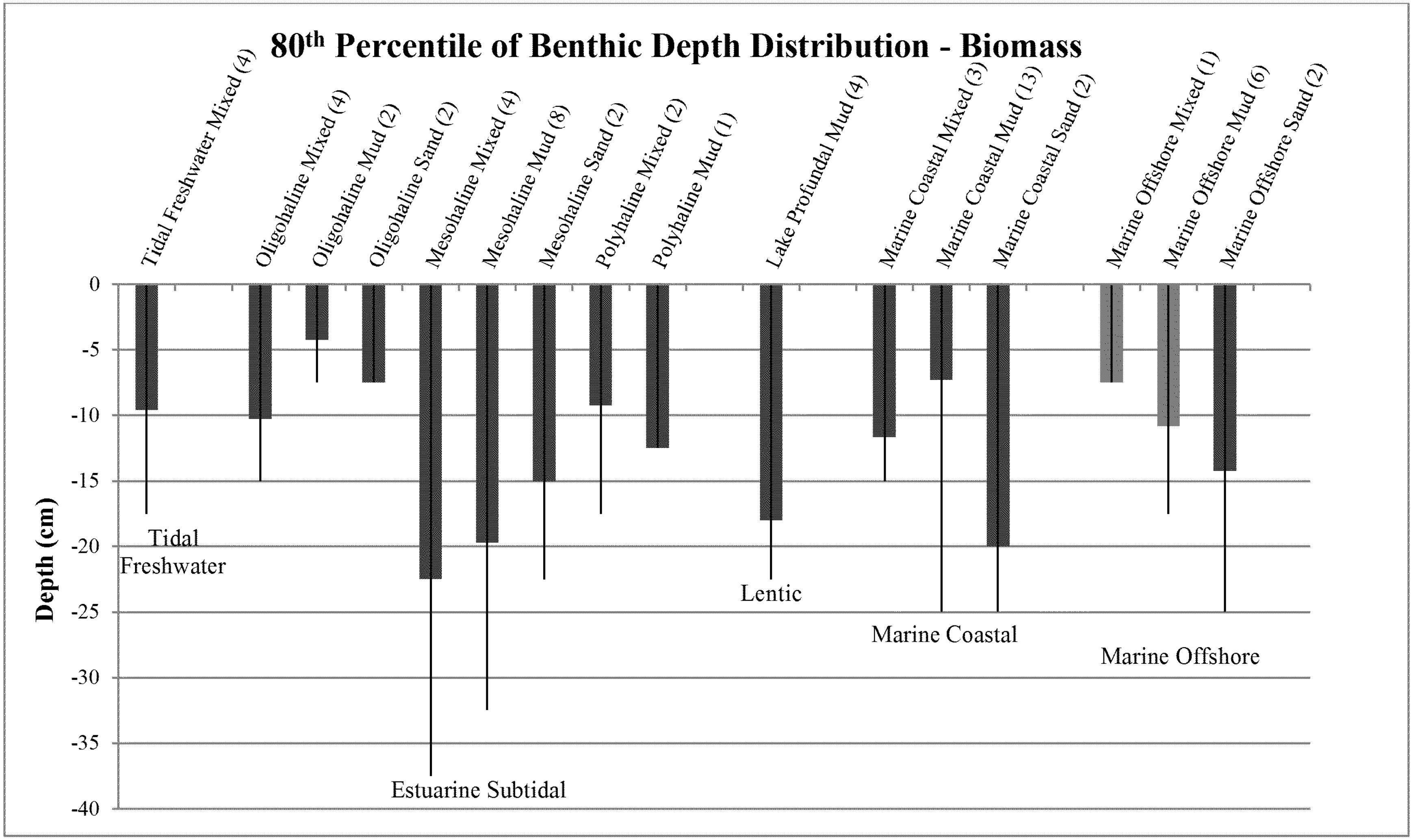

Figure 4. Mean 80th Percentile of Benthic Biomass Depth Distribution (+ Maximum 80th Percentile) in Various Habitats. Number of data sets in parentheses (the number of cores comprising data sets from each habitat type is noted in Table 4). Also see Table 4 for data locations.

APPENDIX

ECOLOGICAL RISK ASSESSMENT SUPPORT CENTER REQUEST FORM

ERASC Request No. 0015
Requestor: Marc Greenberg, Environmental Response Team
Problem Statement: What is a scientifically defensible definition for the depth of the biotic zone in soils and sediments?
Background: We are frequently faced with the challenge of defining the "biotic zone" in soils and sediments during the design and interpretation of soil and sediment sampling programs. This may pose challenges later when we evaluate sediment concentrations (e.g., depth-integrated, mass per unit area, surface-weighting, etc.), calculate or model current and future risks to ecological receptors and humans, and attempt to delineate the relevant depth for remediation at sites where an action is needed. This can have large implications on the cost, protectiveness, and effectiveness of a selected remedy (e.g., capping, dredging, monitored natural recovery, excavation, etc.). Other terms used to describe the biotic zone include "ecologically-relevant zone," "biologically-active zone" and "bioturbation zone."
Expected Outcome: The ERASC should develop a document that will provide a defensible approximation or a range of reasonable approximations for what the depth of the biotic zone is within certain environments. For example, there are those who assume that 4 cm is adequate to define the biotic zone for sediment benthos. Others would argue that 0-2 cm, 10 cm (6 in.) or even as far as 12 in. are reasonable. We need some clarity.
Additional Comments: For sediments, this question should be answered with a primary focus on benthic macroinvertebrates (e.g., bugs and bivalves) and their distribution among various sediment microhabitats. The reason for focusing on benthic macroinvertebrates is because they are measurement endpoints that provide decision-oriented data. The document should provide general explanations of the biotic zone in various aquatic habitats (e.g., stream, river, lake, coastal, estuarine environments) where a remediation may occur. For soils, the focus should be on both invertebrates and vertebrate receptors.